THE BOON OF THE ATOM

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by

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AUTHOR'S NOTE

I am a doctor, more conversant with the work of the physician than that of the physicist, and that may not seem a sound qualification for writing a book some of whose chapters deal with the nature of the atom. But I have done so in a full knowledge of that handicap. My account is that of a plain man with some general knowledge of science and it may, therefore, have some small merits which descriptions by the more technically accomplished might lack. To its making has gone the help of good friends, expert in this field. I do not wish to embarrass them by associating them by name with this work of mine, wherein the guilt for the errors, if such there be, is mine, and mine alone. I ask them to take this, my expression of thanks, in that spirit.

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CHAPTER ONE

ATOMS AND MAN

Until the first atomic-energy bombs fell on Hiroshima and Nagasaki, the atom and its behaviour had been remote from everyday affairs. There was something queer and incomprehensible about them, and when scientists talked of an 'uncertainty principle', there were not a few commonsense men and women who felt that the whole business was a great uncertainty that had little to do with their ordinary lives.

The atomic bombing of Japan did not resolve that incomprehensibility; various articles and talks in explanation served largely to make the fog deeper. But it was realized that the atom and its ways were no longer something apart from everyday life, and that something new and terrible and devastating had been added to the long list of man's victories over Nature. So the idea grew up that, as it was, the product of long years at atomic research had led only to a fresh weapon of destruction more powerful than any known before. The plain man sighed and asked himself, as he had so often done before, 'Is this all science can give us?'

It is to do something to correct this understandable but erroneous view that this little book has been prepared. It seeks to set out the truth about the atom, to dispel, it may be, a little of the fog surrounding it, and to show that, sensational though the atomic bomb is, it is neither the first nor the greatest of the fruits of man's examination of

the atom. An extreme view is almost always a false one; and the idea—fostered in recent years by writers of sensational stories—that in the atom lie the seeds of man's inevitable extinction is both violently extreme and demonstrably false.

Today, when we are only just on the very threshold of full atomic knowledge, research has conferred untold benefits on mankind—benefits that are being utilized daily in saving lives, alleviating pain, and contributing to the day-to-day comfort of us all. The destruction wrought by the atomic bombs has thrown up a cloud, which obscures these beneficial items. It is time that cloud was blown away and the whole subject seen in proper perspective.

The key to the whole thing is to realize what has happened. In the atomic bomb, man has made use of a hitherto unexploited form of energy. Because that use was in war, it was pre-eminently destructive. But that does not make all atomic energy and its offshoots destructive. The destructive is only the purpose for which man has so far utilized it.

Let us take an analogy. In this war, soldiers, sailors, airmen, and civilians alike have suffered from the ghastly effects of T.N.T. and other high-explosives. Cities have been wrecked, lives blasted, aeroplanes shot from the sky, ships sent to the bottom of the sea. But explosives are only a form of releasing energy—in this case chemical energy. Without their aid there could have been no Simplon Tunnel; there would be little stone with which to make our buildings, little coal to feed our furnaces and our domestic grates. Unless there had been long research into the chemistry of explosions and burning generally, we should have no fast cars to take us speedily from our homes to the countryside or the sea, no aeroplanes to carry us swiftly across the continents and oceans, no motor buses to bear us prosaically on our daily affairs, no oil engines to pump water for the country house and cottage—because the

internal-combustion engine, on which all these things depend, is one that makes use of energy released by chemical burning and explosion. Against the use of explosives in war has to be put the value of explosives in peace. So with atomic energy. It is the end to which discoveries are turned not the discoveries themselves which determine their value to man, whether for good or ill.

A dangerous drug—a poison like strychnine, for example—can be used by the murderer to dispose of his victim; equally it can be employed by the doctor to help men and women in their fight for health. The difficulty implicit in this duality is overcome in the case of drugs by making their purchase for improper use almost impossible. If man so wishes he can take precautions to ensure that the knowledge gained by his researches is not turned to evil purposes.

Because, millions of years ago, a little tarsier-like creature began to use its hands and became inquisitive, the long trail of evolution towards man began. Today, we, the descendants of that creature, still use our hands and have the bump of inquisitiveness. Those things are among man's characteristic features. He wants to know and find out; and no-one can put a stop to his efforts. Every year he delves deeper and deeper into the secrets of Nature and his responsibilities grow more serious. Just as the individual has, after thousands of years, come largely to control his instincts by the use of reason, so now, in an age of mass production and machines, collective reason must control mass hysteria and mass instinct. That is the problem. The atomic bomb has only thrown it into higher relief than ever before so that it can be more clearly seen. A danger vividly perceived is one that is more likely to be avoided than a partly hidden one.

But our main object is not to point out and discuss in detail the social and ethical implications of the atom

bomb. We are only seeking here to put the subject in its proper perspective so that it takes its right place in the affairs of men. In particular we want to set out the boons that atomic research has conferred on man so that they may be put into the opposite scale and weighed against the horrors that the atomic bombs have wrought.

In the following pages we shall deal with these benefits in the field of medicine, more particularly—for it is precisely in this sphere that so much has come of atomic research. But it may be as well here to glance at some of the other aspects of the question.

In the atomic bomb, man is making use of the fundamental energy process of the universe. He has used it for destructive purposes, but that is largely an accident of the time and place. All around we have abundant evidence that without this energy, life itself could not exist. The universe would become a dead thing.

Without the sun and its heat and light there could be no life. It is the sun's rays which give us our food and enable us to keep alive and healthy. Without the sun, there would be no warmth. The terrific heat of the sun, of which only a small proportion reaches the earth, is due in the first place to a process exactly the same as that which makes the atomic bomb. Matter is broken down into energy—or rather transformed into energy. Untold millions of millions of atoms in the sun release their energy and give forth light and heat, which the rays bring us. (This is not, of course, an absolutely technically accurate statement of the process, but it will serve.) Through atomic energy, therefore, Nature has given the world life. This is a significant thought.

If we look at the sky on a clear night, millions of stars twinkle at us. The nearest is a very remote thing, as human measurements go. The farthest is so far away that we cannot conceive its distance in terms of our own little

scales. But here, in these little pinpoints, the same process is going on.

Throughout the universe, therefore, this fundamental energy-production goes on ceaselessly. Indeed, it *is* the universe. Why, then, should we be afraid if now we have the means of harnessing this great process, in however small a degree, to our own uses?

These are high matters, and much concern with them is as yet little more than speculation. But nearer at hand, on a more modest scale, we have a lot to thank atomic research for in our daily lives.

When the first conception of the modern atom came into being, a great impetus was given to the whole of science and invention. The whole mode of scientific thought was, in fact, changed. Practical results followed quickly on discovery.

It was research into the atom and its nature that led to the thermionic valve and the photo-electric cell. By means of these we have a whole host of useful and beneficial things. They have made possible our wireless sets and our television receivers. They have given us radar, the use of which for peaceful ends is surely no less than its value in war. The thermionic valve, which glows so dully and looks so unsensational in our radio sets, is the basis of a whole new branch of electrical engineering. Another product of atomic physics is the new forms of lighting which are becoming available—the so-called discharge lamps. At present they are known chiefly in our streets, where the harsh violet of the mercury lamp and the orange yellow of the sodium play queer tricks with colours; in a little while we shall have similar lamps in our homes that give an almost exact substitute for daylight.

The discovery of radioactivity was one of the foundation stones of atomic research. It led in turn to the isolation of radium. Today radium is one of the most valuable

elements in the world's composition. That value is due commercially to its rarity—yes. But it has a higher value than pounds, shillings, and pence. It has brought relief and cure to many suffering persons. One might claim, not without justification, that in radium alone atomic research has given us something capable of saving more lives than the atomic bombs have destroyed. It is a thought well worth serious consideration.

There are other things—X-ray and other ray treatments and applications. The potentialities of radium treatment and its allies have been increased by the production of virtually new elements—all by atomic research. These will be considered in more detail later, and there is no need to do more than mention them here.

Add all these things together—the medical, which are the subject of this book, and the non-medical, which we can no more than mention in passing and then incompletely—and it has to be confessed that roughly fifty years of atomic research have a very creditable record. That record must not be forgotten when we stand appalled and numbed by the destruction caused by the two atomic bombs.

For the release of nuclear energy—which is the proper way to describe the action of the atomic bomb—is not something entirely new and staggering, the discovery of which war forced on us. It is merely the latest step in a long and orderly process of evolution and research. Knowledge has been built up, step by step, over half a century or so; and that knowledge, in itself, is based on what was known before. Nor is the atomic bomb the last step, though it is certainly the latest. More steps lie ahead. How many we do not know—we cannot know. It is probably not the destiny of man ever to attain finality in his knowledge of Nature.

The possibilities of atomic energy have long been the subject of something more than speculation. Years ago

the amounts of energy available could be calculated. They were there, but we had to find the key to release them. The key has been found—and also some means of controlling the energy. The next steps then, will be in the direction of greater control, so that the energy comes forth not in one cataclysmic sweep but in ordered doses, like the impulse of a piston in a motor-car engine.

It is not our purpose here to speculate on the future of atomic energy. That has long been the sport of writers of scientific romance; and it may be because they have so often forecast doom that the impact of the real discovery has so shocked the world. Yet there was one great mind that foresaw something else than destruction in the final conquest of atomic energy.

Nearly twenty years ago, Karel Capek wrote a book called *The Absolute at Large*. He foresaw the release of atomic energy, but argued that as it was the fundamental, it carried with it something of the absolute—the spirit of goodness and plenty, even though he prophesied that it would end in world-war. Perhaps there is more than an allegory in this. Perhaps in atomic energy there is a force for good and plenty beyond our present limited vision.

Let us hope that that is so. But our concern is not with speculations. We do not need to try to console ourselves for the horrors of the atomic bomb by imagination of possible good to come along. We repeat that the credit side of the atomic ledger already has a list of notable and substantial entries. It is those which we shall examine, confident in the belief that the tale already is long enough to offset the debit. But before we can do that with any confidence we must know a little of what the atom and its constituent parts are. It is not so difficult as it seems, once certain principles are grasped, and it has fascinations all its own—the fascination of a new world where old values and old ideas go largely by the board.

CHAPTER TWO

DEGREES OF LITTLENESS

When we start looking into the problems of modern subatomic physics, we are really seeking for the answers to two of the oldest questions with which man has concerned himself in his philosophical moments of speculation: What is matter?—and, again, What is energy? It was during that period so rich in scientific thought, the fifth and sixth centuries of the pre-Christian era, that the first real ideas of which we have exact records took shape, and the schools of thought were soon divided into two sharply contrasting camps. On the one hand were those who affirmed that matter was homogeneous—that one could go on dividing it and dividing it indefinitely and that the only limit to the smallness of the piece obtained was the degree of skill available. On the other hand were those who contended that the components of matter were ultimately infinitely small particles, which were arranged and re-arranged to form all known substances.

The Greeks of this early period were far more akin to ourselves in their outlook than the later Greeks, far better known, were. They saw the connection between physical events and practical experience and tried to connect the two. Their theories were based, to some extent at least, on what we now call experimental evidence. The later Greeks preferred to ignore the test of hard experience (which meant indulging the indignity of manual labour,

fit only for slaves) and maintained the truth of any proposition could be proved or disproved by logic alone.

It was one of these early Greeks who gave us that word 'atom' of which so much is now heard; and he outlined the first really consistent theory of matter. This was Deomocritus, whose atomic hypothesis foreshadowed in some very remarkable ways the 'atomic' theory which Dalton was to put forward fourteen centuries later and which is today, in a modified form, the basis of all our chemistry. This similarity has all too often been too strongly stressed as an example of the adage that 'there is nothing new under the sun'. The similarity is, in fact, largely coincidence. Deomocritus, though not without experimental material, arrived at his result mainly by speculation. Dalton's theory was the statement of an underlying law he had perceived in the rich and ever-growing results in chemical experiment in his period. Deomocritus's theory was lost in the succeeding centuries under the influence of classical Greek thought and eventually the idea current in the Dark and Middle Ages that Aristotle, who rejected it, had said the last word on all scientific matters.

The real beginning of modern atomic theory lies with Dalton who, at the end of the eighteenth century, formulated the modern idea of an element as a substance which cannot be altered by chemical means. Compounds can be broken down into elements, which can themselves be assembled in various ways to form compounds. The 'atoms' of the various elements were held to be distinct from each other, and each to have its own characteristic weight. Later it was found that there were about ninety-two of these elements.

This was the scientific statement of the discontinuity of matter—the theory, based on sound experimental fact, that there are elementary substances of which all matter

is composed. But it was soon found that there were difficulties in the way of the new theory—difficulties arising chiefly on mathematical grounds, since sometimes it became necessary to take into consideration half-atoms; and if the atom were indivisible, that was clearly impossible. Hence there came into existence the idea of the molecule, which may consist of one, two, or—in some organic compounds—a very large number of atoms. It was in these molecules that matter existed, though when chemical reactions took place the atoms broke away either to exist by themselves or form new compounds.

Very little was known about these atoms, except that their various weights were determined with more or less accuracy during the nineteenth century. It was assumed that, like the atoms of Deomocritus, they were featureless and individual, little pellets or balls that could not be destroyed in any way, and that by some process not understood they had the power of giving different properties to the matter they composed, so that lead, a heavy metal, was not like hydrogen, the lightest gas known. As Lucretius, a much later classical follower of Deomocritus said of the atoms, they were 'strong in their solid singleness'.

Until the second half of the nineteenth century it was accepted that the atoms were strongly individual with nothing in common. But knowledge was growing. It was pointed out that the properties of the various elements repeated themselves with some similarity, and that if they were arranged in order of their atomic weights, starting from hydrogen, the lightest, to uranium, the heaviest, these similarities repeated themselves after every eighth element. The rule of eight is not exact, though it is approximately so, and it was left to Mendeleef, a Russian chemist, to draw up the periodic table, as it is now known, in which the elements were arranged in order of their repeating similarities. He did so with great confidence,

filling in the gaps in his table by suggesting unknown elements with certain properties; and when one of these was discovered, the truth of the table of periodic repetition was accepted. It had its mysteries; in places the elements had to be shifted from their proper place according to their weight. On the whole, however, the table agreed with experiment and could be used to forecast results—the proof of any scientific theory.

This progress cast doubts on the view that the various elements were distinct. Obviously, if there was so much recurring similarity between them, there must be some unifying principle. The suggestion was made that the atom itself, the strong and indivisible, was itself complex, like the molecule, and that the atoms themselves were different arrangements of these smaller-than-the-atom particles. Because it had been discovered that, within very close limits, all atomic weights were simply multiples of the atomic weight of the hydrogen, the theory was put forward that all elements might be built up of hydrogen atoms. This proposal, however, found no proof.

Meanwhile, research by the famous Faraday, and others, had brought to light some sort of connection between electricity and atomic behaviour. Furthermore, facts accumulated to show that electricity itself must have a corpuscular character—that is to say, it was not some mysterious fluid, as had been supposed, but was built of small, self-contained units, just like matter itself.

The link between all these results was made by Sir J. J. Thomson, of Cambridge, at the end of the nineteenth century. He discovered the particle of negative electricity, the smallest and indivisible unit charge, and he called it the 'electron'. These electrons were emitted from radiant matter, and all had precisely the same charge. They were indeed the absolute and unchanging and the universal constituent of all matter.

With this discovery the long roads of approach to atomic physics had been traversed. The gates of a new world had been thrown open, and research workers flocked eagerly into it.

We have been talking of 'molecules' and 'atoms', and now we have reached the electron. These are the three main degrees of littleness. Before we try to indicate what sizes are involved, let us try and put them in their place.

The molecule is the biggest of the three particles we have so far met. It is the grouping of atoms of which most matter is normally composed. Sometimes, as in the molecule of protein, one of the constituents of the human body, it is very complex and very large, only just outside the range of the most powerful microscopes. At other times, it is small and simple, like the molecule of water, which consists, as most people know today, of two atoms of hydrogen linked together with one atom of oxygen—the well-known H_2O. When chemical reactions take place, the atoms of the molecules split apart and form new grounds and new substances. There are some molecules that act as though they were single units in most cases; they are known as radicals; they are very frequent in organic chemistry.

Next in decreasing order of size comes the atom. This is the brick of which elements are made. No chemical treatment can break it apart. Chemistry can make it combine with other atoms or molecules, but it cannot split it into more simple particles. With the atom chemistry in the true sense ceases.

Finally, in our knowledge so far, there is the electron. This is found in all matter, and it is the unit charge of electricity. With it we enter the realm of the infinitely small.

Is it possible to assign sizes to these tiny particles? It is, but it is true also that it is a very difficult task. The sizes

involved are as small as astronomical distances are vast. An atom of hydrogen is known to be one hundred-millionth of a centimetre in diameter (assuming it to be circular)—which really conveys very little. This illustration may, however, help. It is given by Dr. G. K. T. Conn in his book *The Nature of the Atom*: '. . . If we magnified an atom to be the size of a pea say one centimetre in diameter, then a little box of sides one centimetre long . . . would have grown to a box of sides ten thousand kilometres long—about the diameter of the earth; the number of peas in this box is about ten million times the population of the earth.'

The atom, then, is to a pea as a pea to the diameter of the earth—a truly minute affair. But how much smaller still is the electron! For this it is impossible to give even a rough comparison of size; the best way is to regard it as a point, an electric charge, that has no size. Yet its weight and charge have been carefully determined. Take our hydrogen atom, the lightest element in the whole series. Of that minute weight, the electron is only 1/1800th.

To attempt to visualize either sizes and weights of these particles is impossible and it really serves little purpose. All these things are relative. To us, the earth is large, but to any supernormal being brought up on one of the larger stars, the earth would be no more than a speck.

But there is one important point to remember and forgetting it is the cause of a great deal of confusion and misunderstanding in popular expositions of the atom. All the sizes and distances concerned are minutely small. Because this is so any idea that they must behave in the same way as the massive things with which we are daily concerned must lead us into errors. Turn again to an astronomical analogy. In everyday life we use the geometry of Euclid for our measurements—and it works well enough. But it is based on the assumption that the earth

is flat. When the astronomer considers the vast spaces of the universe he discards his Euclid. So, when we delve into the recesses of the atom at the other extreme, we must be careful not to believe too strongly that particles we cannot see, that are beyond the possibilities of being seen in the accepted sense, must act as if, for example, they were billiard balls rolling about on a flat table.

CHAPTER THREE

CLOSE-UP OF THE ATOM

The discovery of the electron put an end to the old idea that the atom was the smallest and fundamental constituent of matter. Was its place to be taken by the newly discovered particle? Here fresh difficulties arose. Obviously, the electron could not be the unit from which all else in the world was made. It was practically without weight; and the main characteristic of matter is mass—roughly, weight. Again there was such a thing as positive electricity, and the electron was quite decidedly negative. All matter is inert, electrically, when in a normal condition. Therefore, there must be some positively charged particle to balance the negative charge of the electron.

It was already known that, under certain conditions, as when an electric current is passed through a solution, atoms could become positively charged electrically. Hence the idea was formed that these ions, as they are called—these charged atoms—must be atoms from which an electron or electrons had been removed, leaving the positive part with an unbalanced charge. Moreover, this unit must contain, to all intents and purposes, the whole of the mass of the atom, since the removal of the electron or electrons made no sensible difference to the whole. So, quickly, the positive particle was discovered. It was found to be the ion of hydrogen, the simplest and lightest element known, and to it was given the special name of proton. This

particle has a single positive charge. In the normal hydrogen atom, that positive charge is balanced by the presence of a single electron.

Now it seemed the component parts of matter were assembled. They were like the parts in a boy's constructional toy: standard units from which all manner of things could be made. Electrons and protons combined to form chains of atoms, of varying relative weights and widely differing chemical properties—though those properties were grouped into families with strong resemblances—and the atoms, in turn, could be assembled into molecules ranging from the simple to the highly complex, like the proteins of the human body. And from molecules all matter, as we sense it every day, was made up.

The questions did not end there. All manner of problems arose as the matter was looked into more closely. Models of the atom were constructed, showing how the electrons and protons might be assembled. Each seemed a near approximation to the truth—till some new fact caused it to be altered. In this work, the name of a great New Zealand scientist, the late Lord Rutherford, who directed a brilliant team at the Cavendish Laboratory at Cambridge, after previous work on the same lines in Manchester and Canada, is outstanding; and coupled with his name is that of Niels Bohr, the Danish physicist. Today, the accepted model of the atom is that known as the Rutherford-Bohr atom.

There is not the space here, nor is it necessary, to describe the twists and turns of research into atomic structure. At each step it grew more involved. New concepts had to be introduced to explain anomalies. The subject grew increasingly mathematical and abstruse. It is perhaps because so many attempts have been made to translate some of these purely mathematical conceptions into the bread-and-butter language of every day that the idea has become

prevalent that the atom and the electron and the whole subject of atomic physics is a kind of magical mumbo-jumbo. It is not so.

Before passing on to a rough outline of the atom as it is pictured today, so entering on the last stage of this brief and rapid journey, it may be as well to stress one or two fundamental points about science in general and this subject in particular.

First of all then, science today makes no claims to 'explain' in terms of absolute causes, as nineteenth-century science did—or, rather, the science that sprang from Newton's discoveries and theories. The claim of modern science is that it *describes*. At the back of its mind is always the reservation *as if*. So, if we say, for example, that an electron revolves round a proton, it must be recognized that that is only a mental picture, a possible description: more exactly we should say, 'It is *as if* an electron revolves round the proton—if we imagine that, we get a description that fits with what we know'. Later knowledge, as has happened repeatedly in subatomic research, has caused the picture to be redrawn. Modern science is, in fact, not the dogmatic thing so many consider it to be. Today it emphasizes probabilities, not certainties. When it comes to things like the electron, which cannot be seen directly and whose very nature is obscure, certainty is beyond the powers of human thought. 'The modern physicist', said the later Sir Arthur Eddington, one of the most brilliant expositors of contemporary science, 'makes mistakes, but he does not make hypotheses.'

In this way, when we speak of a 'model of the electron', it is not something that we can make with little balls of wax and lengths of wire or string. The day of the mechanical model as the be-all and end-all of science died with its greatest exponent, Lord Kelvin. Today, the physicist is content if he can reduce what he knows to a mathe-

matical formula. His models are convenient—that is all. No one better realizes than he does the utter impossibility of representing the ways of the electron and the proton by massive objects such as those we can see and feel. The pea and the electron belong to different worlds, though we may sometimes class them together for comparison to bring out one particular point of argument.

As a final illustration of this, take the often quoted case of light. A good deal of caustic comment has been passed by laymen on the fact that today scientists sometimes regard light as coming to us and behaving like a series of waves, and at another time treat it as a stream of minute particles ejected from the sun like bullets from a machine-gun. The wave concept describes some things; the particle theory others. And there is nothing really incompatible between the two ideas, which can be reconciled mathematically. We come back to that '*as if*'. 'In this instance', says the physicist, 'light behaves *as if* it were a wave motion; in that, it behaves *as if* it were a stream of particles.' There is nothing absurd or paradoxical in these apparent incompatibles; they arise simply because we are using, for convenience, a description in terms of common experience for things which are beyond our common experience.

With those thoughts in mind we can walk more surely among the curious exhibits in the atomic gallery. We shall understand that our 'models' are only mental images created by ourselves and made to fit certain observed phenomena.

Now for the close-up of the atom as it is described today. The Rutherford-Bohr atom, in its essential details, has not been changed very much since its first conception a quarter of a century ago; but various refinements have been added, some of them too subtle to demand notice here.

In the atom, then, there is a central nucleus, wherein most of the mass of the atom is contained. Round this core are arranged one or more electrons, revolving in orbits like the earth round the sun. The nucleus, where the protons are placed, has a positive charge equal to the number of protons present in it. The number of electrons in the orbits exactly balances this positive charge. If, therefore, the positive charge on the nucleus is eight, there are eight electrons. In hydrogen, there is one proton as the atomic nucleus; so there is one electron revolving round it.

How is this nucleus made up? This is a vital point. The proton has a unit positive electric charge and, to all intents and purposes, unit weight. If, therefore, the nucleus be composed of protons only, the atomic weight should be equal to the charge on the nucleus. Experiment shows that it is not, but that many elements have a weight in excess of their nuclear positive electric charge. The oxygen atom, for example, has a charge of eight and an atomic weight of sixteen. It was difficult to see where this extra weight came from—in the case quoted, twice as much as the charge. For a long time it was thought that the extra weight came from extra number of protons, each with an electron attached to it to neutralize its charge. It was an unsatisfactory idea for many reasons, and the mystery was cleared up by the discovery in 1931 of the neutron, a particle of the same mass as the proton but carrying no charge. So nowadays the accepted description is that the oxygen atom, just referred to, has a nucleus in which there are eight protons, to give it its charge of eight, and eight neutrons to bring the weight up to sixteen.

The new conception cleared up a lot of problems. It was found that the characteristics of any element depended on its nuclear charge, not on its weight. This resolved the problems of the periodic table, for if the

elements were arranged in order of their increasing charges instead of weight the gradual change and repetition of properties was perfectly regular. If the nucleus loses, for whatever reason, one or more of its neutrons, so that its charge remains the same though its weight is less, the chemical behaviour of the atom in question is unchanged.

Atoms which retain the same charge—that is, are chemically indistinguishable one from the other, but differ in atomic weight—are known as isotopes. The best-known and most striking of these is the isotope of hydrogen which goes to form heavy water. Normal water consists of two atoms of hydrogen associated with one atom of oxygen—H_2O. In heavy water, the hydrogen is an isotope, having a neutron in the nucleus as well as the proton, so that its atomic weight is two, though its charge is still one. To this nucleus, the special name of deuteron has been given and the special symbol D. Heavy water is thus D_2O.

All this looks a little complicated, but it is really quite simple if it be remembered that what makes an element is simply the amount of the charge on the nucleus. Theoretically, an element can have any weight, though in practice the range known is quite small for any particular one. A freak atom of the imagination might have a dozen neutrons in the nucleus and one proton. Its atomic weight would be thirteen, but its charge would still be one; and chemically it would still be hydrogen.

The important points to remember are that the atom consists of a central nucleus in which are protons and neutrons, and that the positive charge of the number of protons is balanced by the negative charge of the number of electrons revolving in orbits outside. If the atom loses one or more electrons, it becomes positively charged; if it gains, for some reason, an additional electron it becomes negatively charged, because there is one too many electrons for the number of protons. In either case, the atom

is still chemically the same element. A hydrogen ion is still hydrogen. So, too, if the nucleus loses or gains a neutron, causing its atomic weight to decrease or increase, the atom remains chemically unaltered, because the charge has not been affected.

What happens when the atomic nucleus loses or gains a proton, so that the value of its charge is altered, will form the subject of the next chapter, though it is obvious, from what has been said, that the principal thing is the alteration of the chemical properties. Before passing on to this fascinating topic, which leads us straight to atomic energy, let us pass in review the particles or components that make up the atom. (That word 'particle' is the one most frequently used, but it is not strictly accurate. The electron must never be imagined as an ultra-ultra-microscopical speck of dust.)

There is the electron, the unit of negative electricity, of utterly negligible weight, less than 1/1800 of the mass of the hydrogen atom, the smallest and lightest atom in Nature. Its charge is balanced by that of the proton, which is the nucleus of the hydrogen atom; this has a unit positive charge and approximately unit weight. The third member of the family is the neutron, similar to the proton as regards mass, but with no electrical charge.

Of these three components the atom is made with the protons and neutrons concentrated in a nucleus, which may be likened to the sun, and round which revolve electrons, like the planets of the solar system. It is the positive charge of the nucleus which gives an element its chemical properties.

Though they do not concern us in this book, two other particles may be mentioned to give completeness. Their appearance is rare and confined to special occasions. They are the positron, which has unit positive electric charge but the same mass as the electron (now sometimes called

the negatron), of which it is the positive counterpart; and the neutrion, a particle of similar mass to the electron but no charge, thus resembling the neutron. There is also the meson, mesotron, or barytron, a particle of charge equal to the electron, but of much higher mass, but it is a newcomer to the family and not yet fully established.

CHAPTER FOUR

NEWS OF THE NUCLEUS

The first stages of atomic research were devoted to discovering how the atom itself was made up. The second stage, investigating the nature of the heavy nucleus which the earlier experiments had shown to exist, began soon after the 1914–18 war; and it is this stage which has been accelerated under the influence of the war just concluded so as to give us atomic energy in one form —the form of destruction.

'Atomic energy' is not strictly the right term to use; 'nuclear energy' is far better, for it is the release of the energy locked in the nucleus of the atom of Uranium that has given the atomic bomb its devastating power. It is essential, therefore, both for an understanding of this aspect and also to realize how nuclear energy has for years been helping the doctor, to know a little more about this central part of the atom.

With its general composition we are now rather more familiar than we were at the beginning. We have seen in the previous chapters how the atomic nucleus consists of a collection of protons and neutrons, which give it both its characteristic weight and its characteristic chemical properties. We have seen how it can vary its weight by losing a neutron or by gaining one while having its chemical nature unaffected. So much we know. What more is there?

To clear the ground we must know a little about energy. In the text-books, energy is defined as the 'capacity for

doing work'—but in that sense 'work' has a rather special meaning. For our purposes we can say that energy is the ability of a body—a particle, a mass of molecules—to act on something else. That is a loose definition with which the strict scientific purists will disagree, but it will do here —and its strict inaccuracy is fully realized.

For example, a wound spring, like that of a clock, is capable of acting upon a train of wheels and so driving the hands to tell us the time; the spring has potential energy which can be released for a useful purpose. In the cylinder of a steam engine there are millions of molecules in a state of great activity, thrusting this way and that; and their potential energy can be translated into the useful work of pushing the piston to make wheels rotate. Energy can be released gradually, as in the cylinder of a steam engine, or it can be released in one great sweep, as in an explosion, when it is the chemical energy locked up in the molecules that causes the work to be done.

There is also what is known as 'kinetic energy'—the energy that bodies get through being in motion. A speck of dust can be driven so hard by a gust of wind that it will dig itself into glass. During the air-raids many of us became familiar with pieces of glass embedded in solid concrete or brick walls. These pieces were hurled through the air at such a high speed that they had a great deal of kinetic energy. A very light body travelling fast may have as much or greater energy of this kind than a much heavier body moving slowly.

Until the beginning of this century, there were two 'laws' that appeared in all the text-books. One was known as the Law of the Conservation of Mass; the other as the Law of the Conservation of Energy. Nothing could destroy mass, nor could it be created; its sum total in the universe was fixed. If a steel bar rusted away, then the weight of the rust and other products of oxidation was equal to that

of the original bar. So with energy. It was indestructible, uncreatable. The energy in the clock spring came from the energy put into it during winding; and it was converted in due course into driving the hands, moving the wheels, and overcoming friction. When the brakes are applied to a moving vehicle the energy of movement is not destroyed: it is converted into the form of heat. Energy and mass could be converted into other forms of energy and mass, but not destroyed.

Like so many of the 'laws' of Nature based on Newton's theories, these had to be modified. They were true—but not universally. They applied only to the particular scale of existence on which we ourselves live, just as Euclid's geometry is true for practical purposes when we are measuring small distances where we need not take the curvature of the earth into account. The Einstein theory of relativity and the work of a physicist whose name is now part of scientific history, Planck, showed that when velocities became very high, and in the region of the speed of light, energy and mass became interchangeable, and the one could be converted into the other according to a fixed mathematical relationship.

Until very, very recently this seemed possible only when the processes concerned were the vast ones of the universe itself—the behaviour of the stars—or the infinitesimal ones of the atom. That man might imitate them was, indeed, possible, but not probable. We have now seen what can be done by man through the atomic bomb.

The more energy there is locked up in a thing, the greater the power required to release it. A very tightly wound spring requires an effort to start it off, but once it is released it flies apart with great power. Now in the atom there are various energy levels, as they are called. Electrons locked up in some of the energy levels are difficult to displace; those in the lower energy levels are

more easily removed. It is the relative ease or difficulty of displacement that is really the basis of chemical reaction. Some elements have electrons which are easily shifted about, so to speak, to combine with other atoms. In this way, very broadly, chemical compounds and molecules are built up. Chemical processes are concerned with the relatively loosely constructed electron structure of the atom. A current of electricity is simply the shifting of loose electrons through, say, a wire of copper, which has certain electrons easily displaced. Nothing 'flows' from the battery. One pole has a deficiency of negative charges and the electrons shift down the wire to fill up the deficiency, just as air flows into a vacuum.

But when the nucleus is approached, the matter is not nearly so easy. None of the energy available through chemical means is sufficient to break down the resistance of the nucleus. The protons and neutrons are too strongly bound together.

Yet it had been obvious for years that protons could be thrown out of the nucleus—or, rather—combinations of protons. In 1896 Becquerel, working in France, had discovered radioactivity in uranium; it could affect a photographic plate. The Curies, Rutherford, and Professor Soddy, followed up this discovery, and it soon became apparent that what was happening was the ejection of particles or rays not from the atoms, as such, of the radioactive elements, but from the atomic nucleus itself. These 'rays' as they were at first thought to be, had varying powers of penetrating such substances as lead.

There is no need to trace the brilliant and painstaking research in this field, which, allied to the researches of Rutherford and others into atomic composition, brought out the picture of what happens. Briefly, the emanation of radioactive substances is the ejection of particles and radiation from the nucleus. The particles come out in the

form of Alpha-particles—these being nuclei of the element helium, consisting of two neutrons and two protons, helium having a charge of two and a weight of four; and in the form of Beta-particles, which are electrons moving at high speed. There is also an electromagnetic radiation, similar in every way except in wave length, which is very short, to light and wireless waves; this is known as Gamma-radiation.

In radioactivity what is going on is, in fact, the realization of the dream of the old alchemists—the transmutation of elements. For each time an alpha-particle is thrown out, the nuclear charge is reduced by two, while its atomic weight drops by four. When a beta-particle—an electron—is discharged, the atomic weight remains the same, though there is a gain of one in the positive charge on the nucleus. In this way, a regular series of transmutations has been worked out. Thus, uranium, the heaviest known element of charge 92 and weight 238, changes through seventeen stages before reaching the final one of lead, of charge 82 and atomic weight 206. On the way it produces the invaluable radium. Some of the stages in this series exist for only a short time, and this discovery led to the filling of several gaps in the table of elements.

All efforts to control or suppress this radioactivity failed. The explosions in the nucleus, so to speak, continued irrespective of what man might do. But man is inquisitive. He tried to find out more clearly what was going on. The result was the bombardment of substances with the emanations of radioactive substances: that is with protons.

Success came in 1919, when Rutherford, using these alpha-particles, succeeded in discharging protons from nitrogen nuclei. The first man-made transmutation had been achieved. With a more elaborate technique, and using, not natural radioactive emanations, but protons driven at high speed by electrical means, two men of

Rutherford's Cavendish team, Cockcroft and Walton, transmuted lithium into helium.

More and more work was done in this field. Not only were actual transmutations effected, but new isotopes were produced, and some of these were radioactive, a result of great importance, as we shall see later. Fermi, working first in Italy and later in the United States, added a new element to the table of elements. Hitherto, uranium had been the heaviest known element, with atomic weight 238 and atomic number, or charge, 92. First, by bombarding this substance, Fermi obtained a new heavy isotope of uranium of weight 239. Bombarding this new substance, he obtained an element of weight 239 and charge 93.

The importance of these experiments is that it was found that many of them were accompanied by a loss of mass and the creation of energy. The actual figures agreed very closely with those which theory had forecast.

It looked now as though a very new and powerful means of energy creation had been placed in the hands of man. He was unlocking the atom at last and setting free those stores of energy which theorists had so long delighted to discuss. But it was not a very practical means of achievement. It might be conducted in the laboratory, but how could it be done on a commercial scale? All manner of difficulties stood in the way, not least that of controlling the released energy in some practical way.

Bombardment by neutrons is, today, the method by which these changes are effected. They are obtained by accelerating them in a device known as cyclotron, which gives energies amounting to millions of volts—another indication of the practical problems involved in the release of atomic energy. The use of neutrons is worth considering in detail for a fuller understanding of the *dénouement*.

The original bombardments were made with alpha-particles, which are positively charged, or swiftly moving protons. But the chance of hitting the nucleus with these streams was small. Rutherford estimated it, in his experiments with alpha-particles, as one in eight million. Apart from the smallness of the target to be hit, the reason for this low probability of a hit is the positive charge of the particle. The nucleus also has a positive charge, and since like electrical charges repel each other, the bombarding particles were thrown aside when they drew near the nucleus. It was only when they were moving very fast that they had sufficient momentum to carry them through this barrier. Neutrons have no charge, and so are not repelled in the same way. The chance of a hit is, therefore, increased.

Even so, however, the results were meagre in comparison with the amounts of energy expended. Any thought of the practical utilization of atomic energy seemed more than remote. It was a hit-and-miss process—literally; and the hits were few in comparison with the misses. Moreover, the only result achieved was precisely that effected by the hit. No other reaction was induced.

But a new development was on the way. Just before the outbreak of war in 1939, the results of some researches by Professor Otto Hahn, in Germany, were made public. He had found, as the result of further work in bombarding uranium with neutrons, carrying on the pioneer researches of Fermi, that under certain conditions the uranium nuclei became unstable. Instead of emitting a particle they split into two parts, and in so doing they lost mass and set free energy. More than that, these daughter parts were themselves unstable and repeated the process of splitting. At each fissure, neutrons were ejected, and these neutrons became bombarding particles in themselves acting on fresh nuclei.

This was a discovery of fundamental importance. It meant that it was possible to induce a cumulative chain reaction in the nucleus, and to start off a process that would grow and grow with immense liberation of energy. It appears that this is what is done in the atomic bomb, in which the speed of the release is slowed down to make it manageable by the introduction of 'filling', which may be deuterons derived from heavy water.

There is, then, nothing entirely new about the atomic bomb. It is rather the result of long years of research marching steadily to a goal. The practical details have been overcome by the intense work of, and unlimited resources placed at the disposal of, scientists.

Whence comes the terrific energy released in this form of nuclear disintegration? In part from the transformation of mass into energy. It is noteworthy that Uranium 239, the heavy isotope of uranium, is used for the bomb; its disintegration would be associated with loss of weight and freeing of energy as compensation. But there is another and important aspect to consider.

Let us look again at the composition of the nucleus. There are protons and neutrons in each atomic nucleus. In the uranium nucleus there are ninety-two protons, for that is the amount of its positive charge. But each of these protons is a unit of positive electricity and each is like the other. Now though the nucleus is the largest individual part of the atom it is inconceivably small, and hence we have the very extraordinary fact that within this minute compass ninety-two positive charges can exist alongside each other in a state of comparative stability. By all the ordinary laws of electricity they should fly apart when they came within ranges far greater than the diameter of the nucleus.

Clearly the laws of electrical attraction are broken down here by some force greater than them. Without such a

force, the whole world would fall to pieces. It is a force which, as has been remarked, is greater than gravity in every sense. How much this force must amount to has been calculated, but it is so vast that it cannot be expressed in conceivable figures. Professor Grew, however, has said that if the force of gravity were stepped up to the same degree of power as that keeping the protons in the nucleus together, a feather on the earth's surface would weigh a billion—a million million—tons. It is a stupendous thought.

Some at least of this binding energy must be released when the trigger of atomic disintegration is pulled, and the apparent mystery of the bomb no bigger than a rugby football which blew up Nagasaki is, to that extent, cleared up. The chief problem, indeed, is precisely how this liberation of vast energy has been controlled so far as it has.

Here, then, we have an outline picture of the nucleus and of the energy it contains. In this chapter it has led to the atomic bomb. Later in this book it will be shown that some, at least, of the forces involved have been operating in the better interests of man for many years. In the future, it may be, the atomic energy will be harnessed for the more obvious productive and creative work of man. Here and now, however, atomic energy and its offshots are doing valuable work.

In this book the atom is, so to speak, on trial. Publicly it has been arraigned on the score of being a menace to humanity. We have taken evidence, in sketchy outline but sufficient for our purpose, of the character of the accused, and we have referred to the destructive powers on which the indictment is based. The next step is to bring forward the evidence in favour of the accused. It is not so unimpressive as some would have us believe.

CHAPTER FIVE

THE PRACTICAL PICTURE

The story of the growth of atomic knowledge as outlined so far seems very remote from everyday life. It is an abstruse matter, it seems, barely capable of being expressed in ordinary language. The only practical outcome of all this work is, it appears, just one more means of destroying human life and property on a vaster scale than ever before. Of what practical use to man has been all this research and discovery, which have brought to light particles or bodies—call them what you will—of inconceivable minuteness?

It is no wonder that this general attitude to atomic research has come about. The theory of it is utterly divorced from the daily affairs of the world, with its mathematical concepts, its axiom that the laws of Nature as we have come to recognize them find here startling exceptions. Interesting enough, no doubt, to read about in the library or by the fire on a cold winter's evening. But surely there is nothing more in it than that.

This type of view is always apt to arise when a subject is approached solely from the theoretical side. It is inevitable that it should be so for the whole object of scientific theory is to get away from the shackling realities of practice. The research scientist seeks fundamental principles. He sees a windmill at work and notices that it reacts to the wind in various ways. He finds that aeroplanes behave in very similar ways. So he tries to find the

underlying principle quite irrespective whether it is aeroplanes or windmills or ventilating fans that are the immediate source of information and practical interest. As a result there come formulae and scientific statements. The reader finding these could be excused if he imagined that the subject of air in motion had no practical value to him in the grim business of wresting a living from the modern world.

Really, to approach a subject from the theoretical side is to put last things first. Theories come after practical applications. There were windmills long before there was a science of aerodynamics. The men who built the old tower mills of the English shires, the mills that for so long provided rich, stone-ground flour for the people, knew nothing at all about what are now called aerofoil theories. Men had even learnt to fly before any scientific basis had been established for all they did in the air. Theory is an abstraction from practice, a statement of principles in what are believed to be fundamental terms.

In atomic research the astonishing discoveries of the laboratory have tended to divert attention from the practical applications. The atomic bomb burst upon the world as apparently the first achievement of these years of theoretical advance which had upset the old Newtonian laws of physics and turned upside down many a cherished idea in its head. For practically half a century, it seemed, man had been prying into the basic secrets of Nature and all he had found was a method of wreaking more havoc than had ever been caused before.

The point that emerges from all this is that there has been this half-century of research—itself the outcome of other work before. It has grown organically. At first, despite current beliefs, practice led the way. Atomic physics has never been entirely the laboratory subject so many consider it to be. Often practical discoveries and

uses have provided the groundwork for the apparently abstruse research that has been described in outline here.

At other times, of course, theory has pointed the way. This sort of interaction is common in these days when research is an integral part of industrial activity. It was the mathematical investigations of Clark Maxwell that led to the laboratory experiments of Hertz and the discovery of electromagnetic waves. These in turn stimulated practical inventors like Marconi to develop the early wireless telegraph systems, the practical problems of which repaid the debt by initiating research into a whole new field of electrical phenomena. No one can say precisely where theoretical research and practical applications have their dividing line. The old distinction between pure and applied science, which postulated that laboratory work and practical applications could be carried on in watertight compartments, was based on a fallacy to which little attention is now given.

In the sphere of atomic research this interaction has been very plain. Practice has aided theory, and theory in turn has led the way into new practical achievements. There is scarcely a field of scientific industry in which the effect of modern atomic theory is not felt. One of the most widely used devices today is the electronic or thermionic valve. Its whole basis is the application of atomic theory, though it may be noted that Fleming's discovery of the valve was not a purely theoretical achievement; rather it was one of those in which practical experiment and theory overlapped and joined hands. It would be impossible even to give a catalogue in these pages of the uses to which the thermionic valve is put in practical applications. From the wireless set by the fireside to the systems of world communication, from counting the number of people who enter an exhibition to detecting the presence of flaws in metals, the valve has found uses and today it is made in

a multitude of different forms—a multitude that makes the complicated-looking lists of ordinary wireless valves mere samples.

Radioactivity was a practical experimental discovery that led in effect to the whole new world of atomic physics and the new conception of atomic change. But radium was in practical use long before its theory was elucidated. X-rays remained a theoretical puzzle for a very long time —but they came into practical use in several ways none the less. In both spheres, the results gained in practice fed the fires of research, and they in turn provided fresh energy for the practical applications.

It is a familiar story, but it is as well that the fact should be recognized clearly in relation to atomic research, which for too long has been looked upon as the happy playground of the theorist who need not trouble his head with practical problems.

Since the idea that destruction is the aim of atomic research has recently gained such wide currency, it is heartening to be able to point out that so many of the practical triumphs of atomic physics have been in the field of medicine. Today, indeed, medicine without the aids that atomic physics has given would be unthinkable. The work done here is powerful evidence of the more benign aspects of atomic research, and to these the rest of these pages is principally devoted. If they are not exhaustive— as they cannot be—at least they may do something to put the picture into proper perspective.

CHAPTER SIX

SEEING THE UNSEEN

In the closing decade of the nineteenth century, a great deal of experimental work was being carried out on the discharge of electric currents through tubes from which the contained air was gradually exhausted, and some very important results from the point of view of general physics were obtained. It was through experiments of this kind that Sir J. J. Thomson discovered the electron and thus laid the foundations for a new, and as is now thought, final, knowledge of the structure of matter.

In physical laboratories all over the world work of this kind was going forward, and in Germany Wilhelm Konrad von Röntgen was among the most active researchers. As a result of his experiments he discovered a form of radiation with quite unusual properties. Not only had it the power of passing through the glass of the tube in which it originated, but it also appeared to be able to traverse substances that to ordinary light are quite opaque. He found, for example, that by the aid of X-rays it was possible to 'see' the form of keys and coins in a purse, and from this it was only a short step to 'seeing', in the same way, the bones of the skeleton, the hand being the first part of the human body to be explored.

These rays had several very important properties. Not only did they pass through opaque substances, but also they had the property of causing fluorescence in certain

materials. Thus, if a cardboard screen is coated with barium platino-cyanide, it glows when this radiation is directed onto it. By the use of fluorescent screens of this kind, new facts were discovered about the rays. Thus it was found that they are less able to penetrate some substances than others, metals being especially opaque to them. In this they resembled light rays, which pass through glass easily but find other substances more opaque to them. The bones of the body were of a nature that did not allow the rays to pass freely.

When, therefore, the rays were directed onto a human hand and that hand was held over a fluorescent screen, the pattern of the bones stood out as a sharp shadow, while the flesh, which is more easily penetrated by the rays, appeared shadowy and diffuse, just as gauze appears when lit from behind with ordinary light.

This radiation was quite unlike anything known before and for the time being was a complete mystery. Accordingly Röntgen christened his discovery 'X-rays', *x* being the universal symbol for the unknown, but it is worth noting that while in this country the term X-rays is used almost without exception, on the Continent and in the United States it is more usual to refer to the radiation as Röntgen rays, after its discoverer.

This discovery stimulated research into the character of this and other allied forms of radiation. With the new electron theory then attracting attention, it was thought by some that this must be a new manifestation of a stream of particles; later experiment however showed that X-rays are identical in nature with ordinary light—that is to say they are electromagnetic waves. The only difference between them and light rays, in the usual sense, is that they are of extremely short wave length or, to put it another way, of very high frequency; the waves oscillate very many times every second, though their actual speed in space is

the same as that of light—i.e., about 186,000 miles per second.

As soon as it was proved that these rays had the power of penetrating human flesh and giving a silhouette of the bones on a fluorescent screen, the medical profession recognized that here was a very powerful method of diagnosis available. They did not wait for the clearing up of the theoretical nature of the radiation; they were content to leave the *x* as unknown and make what use they could of the practical effects.

A further effect of the rays was to affect a photographic plate. The plate, wrapped in a black paper envelope so that it should not be fogged by ordinary light, was put in the position usually occupied by the fluorescent screen. The X-rays penetrated through the hand and threw the shadow on the plate, from which a photographic print could eventually be obtained in the usual way. Thus, the doctor had a means of seeing the unseen—of examining such things as fractures of the bones at his leisure and deciding on the best course of treatment. A new page was turned in the history and technique of diagnosis. For the first time actual ocular evidence of what was happening to certain structures inside the human body was available, and the doctor no longer had to depend on the sensitiveness of his touch—a faculty that comes only after long experience. Moreover the need for the surgeon to make exploratory operations for the purpose of discovering what was happening out of sight was rendered less.

Only the bones proved opaque to the rays, though with very light exposures of the plate, some of the structures of other parts could be made out. But a means of exploring the digestive tract was soon evolved. The patient was given a meal in which some substance, such as bismuth, opaque to the rays, is present. The course of the meal can

then be studied, since the bismuth makes it photographable.

Here we may glance ahead a little to see what happened in the more general sphere. Today X-rays are used for examining such things as engineering castings—another example of the way in which theoretical atomic physics has been put to practical use. But more than that, X-rays have given us a much more intimate knowledge of the structure of matter itself. By their aid it has been found possible to explore the way in which crystals are made up—and this, in turn, has provided new knowledge for the main fundamental research.

In medicine, the first use of X-rays was for diagnostic purposes—the obvious use. If they had contributed to practical medicine no more than this, they would have been a brilliant example of how the new physics has benefited man. At that early time little was known of the rays in the medical sense beyond the fact that they enabled certain parts of the body, normally hidden, to be seen and studied. The apparatus was crude and the effects of the rays were obscure. The refinements that the modern radiologist takes more or less for granted were at that period undreamed of.

Quite early, however, it became only too clear that the X-rays had some other and very striking effects on the human body. If it was exposed to their influence too long, undesirable symptoms began to appear—and hence grew up the legend that X-rays were dangerous. Workers in X-rays developed strange conditions. The general deduction was that X-rays had a therapeutic as well as a diagnostic use. From the realization of this fact a whole new section of therapy was opened up.

As medical radiologists made more demands and some sort of general picture of the theory underlying X-ray treatment emerged, new and more powerful apparatus

made its appearance. Research and practice went forward hand in hand, and today radiology is an integral part of modern medical technique.

It will be interesting to consider some of the general benefits before passing on to a more detailed description of some of the major effects and uses of X-rays.

Radiographs are indispensable to the modern physician and surgeon. By the aid of X-rays he can examine fractures and other internal conditions and prepare his operations accordingly so as to get the maximum results in the simplest possible way. By X-rays he can determine the onset of tuberculosis of the lungs—one of the most dreaded and common diseases of today; and here is one example of the life-saving properties of the rays. He can study for practical purposes the workings of the digestive system, while in research he can gain knowledge of that working which is of the greatest benefit for general treatment. It has been said that the X-rays more than anything else have destroyed the old high art of the diagnostician. No doubt it is sad to see something which demanded a very subtle skill deteriorate, yet the gain far outweighs the loss. The X-rays have made it possible for all doctors to obtain accurate knowledge of what is happening in certain states; in the old days, the number of highly skilled diagnosticians was very small and only a few people had access to their services.

The nature of X-rays is very largely determined by the degree to which the air is exhausted in the tube from which they emanate. If the vacuum is high, the penetrative power of the rays is greater; the rays are then said to be hard. On the other hand if the degree of vacuum is low, the rays are 'soft', and they do not penetrate to the deeper levels of the body. This gives a measure of control to the operator. In the old days, any sort of tube that would give the required picture was considered

adequate. Today radiology is a specialized branch of medicine and the choice of hardness or softness of rays, time of application, and so forth, demands as much care and fine judgement as most special medical treatments and techniques.

Apart from hardness and softness, length of exposure to the rays is of great importance. Too long an exposure may induce, as we shall see, very undesirable results. In this respect, so far as diagnosis is concerned, the progress in the production of photographic plates and films has been of the greatest help. High-speed films now make it possible, coupled with more efficient tubes accurately controlled, to obtain the desired results in a small fraction of the time hitherto necessary.

The large field of modern radiology cannot be more than glanced at here, and there is much progress still to be made. One of the latest advances is wide-field X-ray therapy, by means of which much larger areas of the body can now be treated successfully than formerly. This technique is still in its infancy but it promises to afford powerful new treatments in certain affected conditions of the body.

From this general survey, we may pass to a more detailed consideration of the effects and applications of X-rays, surely one of the most beneficial of all the many useful offshoots of modern physical research.

CHAPTER SEVEN

WHAT X-RAYS DO

Perhaps a better title for this chapter would have been 'some of the things X-rays can do', rather than 'what X-rays do', for there is still a great deal to be learnt about their effect on the human body. But much is now known and a brief survey of the general effects gives an indication of how powerful X-rays have become in the medical armoury.

As has been pointed out, the possibilities of X-rays as a therapeutic agent arose from the study of the ill-effects their use occasioned both on those who worked with them and, occasionally, on those patients who were submitted to them for diagnosis. One of the chief discoveries was that the rays penetrated deep into the body, and since one of their effects was obviously some form of breakdown of the cells of which the body is composed, the idea that they might be employed to disperse, for example, such growths as cancer arose quite early in the history of radiology. Not only was it possible to reach places hitherto accessible only by surgical intervention; it was practicable to study effects and so to ensure that the rays actually penetrated to the affected part—a state of affairs that is not always easy to ensure when medicines of the usual kind administered through the mouth or by injection are employed.

Even today, as has been indicated, the full extent of X-rays effect on the human body is not known, but that

does not mean that X-ray therapy is still in the experimental stage and that it should be resorted to only when all other methods fail. The knowledge available today in certain states is at least the equal of that in some other spheres, and dosages can be determined by scientifically sound principles, so that a definite, controlled result is attainable.

Early experimenters found that the X-rays had a direct effect on human tissue—that is to say they influenced the millions of cells of which the body is composed. But more research brought it out that there was not the same effect on all kinds of cells; the X-rays appeared to have a selective action. When this point was taken up and studied more closely, the remarkable fact emerged that X-rays had a greater influence on cells that were reproducing themselves than on others. As is now fairly generally known, the cells of the body, like the minute single-celled living things found in ponds, reproduce themselves by the outwardly simple process of dividing into two to form a couple of new individuals. It is during this state of division that the body cells are found to be most responsive to the influence of X-rays.

Now medically this opened up very encouraging lines of thought. It meant that X-rays would be most potent on growing cells, for it is just then that this process of division is at its maximum. But there was, too, yet another significant discovery. Another selective action came into force. The human body is made up of many different types of cells; it is, so to speak, a great colony in which many different races mingle, each doing its own particular work for which it is best fitted. X-rays have a bigger effect on the more primitive types of cell than on the more complicated ones.

This was a really important discovery. Today, X-rays are best known, apart from their diagnostic applications,

for their use in the treatment of cancer. It is due to this doubly selective action that they can be so used. A cancer is something which is growing very rapidly. It is, roughly speaking, something in which the ordered cell multiplication and replacement of the body has broken down, and the diseased cells increase at a dangerously rapid pace. In addition to this, the cells of a cancerous growth are primitive in kind. They are therefore ideal for reaction to X-rays. Coupled with this is the very interesting fact that the cells from which the body derives its chief nutrition and those which are carrying out their normal functions properly are relatively highly resistant to X-rays unless the time of exposure is very long indeed.

There is no need here to go deeply into the actual effect of the rays on the process of cell reproduction. For its understanding some knowledge of cell biology is required. But it may be said that the general effect of X-rays is to check or completely stop the division. But a great deal depends upon the dosage—and it was lack of knowledge of this fact that led directly to the early failures. The general indication that X-rays had direct influence on the cells was gained from a study of those cases which had had excessive applications, and from this the conclusion was made that the action was always destructive, though it only reached a dangerous point when there was long exposure. Research proved that this is not so.

Actually, there are three kinds of effects on the human cells produced by the radiation. If the dose is small, so far from checking cell reproduction, the rays accelerate it and stimulate growth. Increases of dosage led to a check on the reproductive process and finally, when the doses are large—that is to say, the period of irradiation is long—the cells are destroyed.

This was a further gain in knowledge which has considerably helped forward the science of X-ray therapy.

By using his judgement to combine the different effects of the rays, the radiologist can prescribe the degree and frequency of application which is most likely to ensure the desired results. It is through knowing how to attain this balance that so much progress has been made in recent years in the treatment of tumours and other conditions by the use of X-rays. Further knowledge will undoubtedly increase the effectiveness.

Apart from these local effects of the radiation, there are more general ones on the human body. Cases of pain arising from irritation of the nerves have responded encouragingly to irradiation, and there is much research being carried out in this direction. Precisely why this effect should be is not yet known, but there is evidence to show that the rays reduce the response of the nerves. This is very feasible, since the nervous system is today regarded as being electrical in nature. With this, we are back again to the fundamental nature of electricity in the constitution of all matter, and the interlocking of everything with atomic physics is again demonstrated.

Patients under X-ray treatment frequently experience unpleasant symptoms ranging from nausea to headaches, which is believed to be due to a form of general poisoning arising from the release of broken-down cells into the system. This is one of the things that necessitate the most expert treatment of all cases.

In extreme over-exposure the most serious results are possible. One of the most responsive cells in the body to X-rays is the leucocyte—the white cells of the blood which play so important a part in resisting the invasion of germs into the body. This may go so far as to result in a critical form of anæmia with disastrous prospects for the patient. With modern knowledge, however, the chances of producing such a state are remote, though it was by no means uncommon in the early days.

The modern technique of X-ray therapy is complicated and the apparatus used is varied. All manner of protective devices and methods are adopted to ensure that no part of the body other than the intended one is exposed to the radiation. Care is taken, too, that the radiologist himself, who is working almost every day in the neighbourhood of the rays, is kept from harm. The knowledge on which these protective means are based was gained by bitter experience, principally through what is now known as radio dermatitis, a very painful and sometimes serious inflammation of the skin. If taken in time this condition can be dealt with, but if left undetected or untreated it may develop into ulcers and become chronic, and present knowledge does not permit too strong hopes of cure if this stage is reached.

It is no disparagement of X-ray therapy to point out its dangers and its limitations, for if these are fully recognized the method may be employed to the utmost advantage. In modern practice, the chances of untoward effects on the patient are very, very remote, and workers today are so fully awake to the possible ill-effects on themselves that casualties are few. The known danger is one that can be met; it is the unknown which is the serious menace.

The treatment of cancer, in which growing success is being gained, is the best known and probably the most spectacular application of X-ray therapy. It is now so advanced that many cases which, hitherto, would have been considered ones for surgical operation, can now be dealt with successfully by radiation. But, great though the success won has been and promising though the future outlook is for this treatment, it must never be regarded as either the only one or the best one. The large amount of publicity given to X-ray treatment of cancer has rather tended to promote the belief that this is so. It is only one

among several possible methods, and it is as such that it should be regarded. Cancer is a very terrible disease though not so inevitably fatal as the general belief runs. Provided the appropriate attack is made in time, the chances of ultimate success are much less remote than they used to be.

Many other conditions have, however, also proved responsive to X-ray treatment. Among these are a variety of diseases of the skin, including acne, erysipelas, and ringworm of the scalp. Warts are among the blemishes that yield to X-rays, which are also effective in various kinds of superficial ulcers.

One of the most interesting applications of X-rays is in the treatment of blood conditions. There is a state known as leukaemia in which there is an excessive number of white corpuscles in the blood, the count sometimes being as much as thirty times the normal. This is accompanied by a drop in the number of red cells. This condition is usually typified by an enlarged spleen—for the spleen acts as a reservoir of blood and also plays an important part in the formation of the red corpuscles and also of the white corpuscles. In many of these cases good results follow irradiation of the spleen itself—a fine example of the way in which X-ray therapy may be directed to internal organs without damage to their surroundings. Blood cells are also manufactured in the marrow of the long bones, and these too may be subject to the radiation. The results of this latter treatment are not so conclusive, though they are generally encouraging.

Brain tumours and other diseases of the nervous system, not so very long ago regarded as incurable, also yield to X-ray treatment under favourable conditions, though the cells of the nervous system are among those most resistant in the body to X-rays. Long applications are therefore required and have given satisfactory results.

Abnormal conditions in the body are often created by over-activity of the endocrine glands—the system which produces the hormones that control many of the functions, such as growth and reproduction, of the body. In extreme cases very serious deformity may result. The usual method in cases which can be treated is to remove part of the over-active gland by surgical operation, but X-rays have proved valuable here as well, since it has been found possible in certain instances to reduce the abnormal activity of the involved gland by irradiation. The thyroid and pituitary glands are examples of organs which have responded well to irradiation, especially when they are diseased by tumours.

Another variety of nervous diseases in which X-rays are employed is those of the spinal cord. Even neuritis, one of the most distressing and intractable of complaints, has been at any rate relieved if not cleared up by irradiation, though why this should be so is not yet clear. Once again, however, it seems that the X-rays affect the conductivity of the nerves, and a glimpse is gained of fundamental processes at work.

These are only a few of the diseased conditions to which the modern radiologist turns his attention. There are many others, and the field constantly tends to expand. Later in this book when a glance is taken at possible future developments something will be said of the possible effects of X-rays on heredity. Here it is sufficient to say that it is already certain that X-ray and other forms of irradiation do have a marked effect on heredity and can also have an influence on the unborn young.

A very bald account of the triumphs of X-rays has been here given but it is sufficient to show that they have proved a very beneficial and potentially even more useful application of the new atomic physics. There may be those who contend that X-rays do not form a branch of atomic

physics proper and that therefore this evidence for the defence of the atom is inadmissible. That view is not taken in reviewing the general position. X-rays sprang from the same series of experiments in fundamental physics from which, also, knowledge of the electron was born, and therefore the parentage is the same. Without this research there would be no X-rays, and without the results of X-ray experiments general atomic theory would have been held back in its development. With the next chapter, however, we approach a subject which is much more intimately associated with modern subatomic physics and into which some of the newest discoveries of that science are utilized. For this, a consideration of X-rays has proved a good introduction, apart from the fact that it is historically somewhat senior to radioactivity, to which we now pass on.

CHAPTER EIGHT

NATURE'S PROJECTILES

Radioactivity is something which we have met before in these pages. Its discovery was the door to the new world of the divisible atom, the gateway to the path that has led us to more fundamental knowledge of the structure of the universe than anything before. But in previous chapters we considered it principally from the theoretical point of view; we were simply finding out what it was or what it seemed to be. Now we have to look at it as a useful thing, something that can be turned to good account in the balance sheet of the atom, and not merely entered as the huge debit item of the atomic bomb.

It was Becquerel who made the first exciting discovery almost exactly fifty years ago. He was studying uranium about which little was then known beyond the fact that it was the heaviest of elements and the last in the periodic table. There *might* be elements more massive atomically than this, though it was very doubtful. In any case it was time more was known about it. The heavier elements in the table showed rather surprising anomalies in many ways. It was these which upset the smooth progress of the periodic table of elements when arranged in order of atomic weights, and there were gaps in the highest reaches which so far had not been filled; nor did they seem likely to be filled.

He was prepared to find curiosities about uranium, for it was an extreme element, and extreme types, whether

in elements or human beings, are apt to behave a trifle queerly. At the other end of the table, hydrogen, the lightest element, did some rather odd things as compared with the more stable elements in the respectable middle range. But he was not at all prepared for the surprise which he did find; nor had he any idea that his researches would upset all preconceived notions of the structure of matter. Unwittingly Becquerel was destroying a world hitherto considered stable.

His discovery, as already mentioned, was that in the presence of uranium photographic plates, sealed in dark covers, were affected. This was indeed startling. Investigated, the phenomenon was shown to be due to the emission of particles from the uranium. These, as we now know, were alpha-particles, or the nuclei of helium, consisting of two protons and two neutrons, with charge two and atomic weight four. So much we knew before.

This was the bow of radioactivity upon the stage of human knowledge. Its effects have been far reaching. Through this discovery, many new ideas have come about, as many—or more—old ones been discarded. Coupled with the effect of X-rays on a photographic plate, the discovery that radioactive substances could produce an image on a sensitive emulsion led to a crisis in the theory of light and the ultimate abandonment of the classical wave theory of light as the complete and final description. In some circumstances light behaved as though it was a stream of particles; and some time later, as the result of work by several scientists, among them the famous Einstein, the particle of light known as the photon was conceived.

These facts are mentioned in passing because they show the fundamental importance of Becquerel's discovery. In some ways it might be considered the most momentous ever made by man. Here he was getting to the very root of things, and though he had not yet grasped it, the key

to the working of the universe and with it access to immense sources of energy, was being thrust into his fumbling hand. Newton's enunciation of the law of gravity, often hailed as the greatest discovery of scientific man, is hardly as epoch-making as this. Everyone, ignorant or learned, knew that bodies fell to the ground. Newton formulated an underlying theory; he did not make an absolutely basic discovery such as this.

The work of Becquerel was followed up eagerly by a young Polish-French woman scientist, Marie Curie, who, with her husband, was later to become world famous, even if worldly success in terms of wealth was to escape her. Today, for every ten people who know of the Curies, only one, perhaps, has heard of Becquerel. Yet, without disparaging the work of Curies, which is too great and too lasting ever to be undervalued, Becquerel's was the more sensational achievement. In part, maybe, it was accidental; but so are all fundamental and novel discoveries. A research worker cannot make plans to discover something of whose very existence he is unaware.

Two years after Becquerel has found uranium to be radioactive, Marie Curie discovered radium. This is the radioactive element which, till the coming of the atomic bomb with its uranium basis, was the most famous of all. Because of its value in medicine, it had become the most sought-after thing in the world, for the ores containing it are extremely rare.

So the trail began. We have made some attempt to follow the main lines of that trail in the initial chapters of this book, and the end of the trail is not yet. It may be that it will lead to heights from which may be commanded a vista of knowledge and power beyond man's present imaginings.

Before passing on to the medical aspects of radioactivity—that is, radioactivity in the direct service of man—it may be useful to sum up some of the essential

points and to introduce one or two new ones of importance to us. The first is that radioactivity of uranium, radium and other natural substances, is due to the ejection of particles and rays from the nucleus. It is a nuclear change and not an atomic one. The emission is of three forms: alpha-particles, which are helium nuclei, which act in many ways as though they were self-sufficient entities; beta-particles, or electrons, about which nothing more need now be said; and gamma rays. The last have special significance in medicine. They are not particles as are the other two emissions, but electromagnetic radiation of extremely short wavelength (and, therefore, very high frequency). X-rays, it will be remembered, are an electromagnetic radiation of precisely the same kind, but the gamma rays have a wavelength at least a thousand times shorter than X-rays.

Another point to recall is that when an element emits one of the particles its chemical nature changes—it becomes another element. Uranium breaks down into forms known respectively, as Uranium X_1, Uranium X_2, Uranium II, and Ionium, before it becomes radium; and, in turn, radium proceeds by way of forms known as Radium A, B, C, C_1, D, and E, to polonium and, finally, lead—which because it has a different atomic weight from common lead is, in this case, sometimes known as radium G, with polonium as radium F.

The new point of importance is that the life of these various substances is measured by what is known as the half period. This means that the life is expressed by saying that in such and such a time the radioactivity of the mass will be reduced to one half. Thus uranium X_1 has a half-life of twenty-four days, which means that in twenty-four days its radioactive output will be reduced by one half; and that in a further twenty-four days, it will be less by yet another half; and so on.

Some radioactive substances have very long half-life periods, which means that their decay is very slow. Uranium, for example, has a half-life period of almost inconceivable length; it is put as five thousand million years. Other substances have extremely short half-life periods. For example, Radium A has a half period of three minutes only, while Radium C_1 has a period so short that it has not been accurately measured, though it is put at the unimaginable brevity of one millionth of a second. When there are elements with lives as short as this it is no wonder that so many of them escaped detection, leaving gaps in the periodic table, until radioactive theory directed attention to their probable existence.

As a matter of interest, the uranium-radium-lead series is not the only radioactive one. It has itself a secondary series, for uranium II may break down into either ionium or uranium Y, according to whether it emits an alpha-particle or an electron. There is, too, the thorium series which also eventually arrives at an isotope of lead. But it is the uranium-radium series which is the most important practically. One feature of this series is particularly interesting from the medical point of view. Radium, by emitting both an alpha-particle and a beta-particle, turns into radon, which is a gas and was once known as radium emanation; indeed, many thought it was the actual product of radioactivity. The radon itself becomes the solid radium A. It is the transmutation of radium into radon that gives radium its special place in therapy.

The clue to the therapeutic effect of radioactive substances has already been given. Gamma rays, it has been pointed out, are of the same kind, though differing in wavelength, as X-rays, and hence the effects should be of the same kind, allowing for the difference in frequency. It will be remembered that hard X-rays had greater penetrative power than soft ones and were of shorter

wavelength. Hence, it is not unreasonable to suppose that gamma rays would possess even higher powers of penetration, and this proves to be so. The effect of the radiation is, in fact, precisely similar though of an intenser force to that given by X-rays.

The action of the other emissions also resembles that of X-rays. The beta-particle, which is a fast moving electron, resembles various forms of cathode-ray treatments, while the alpha-particles have, as they stand, comparatively little therapeutic value. This is because they are slow moving and possess, therefore, very small penetrative power. It has, in fact, been demonstrated that alpha-particles can enter human tissue to a depth of only one-tenth of a millimetre, which is quite insufficient for medical purposes.

In theory, therefore, radioactive substances can be employed for precisely the same conditions as those for which X-rays are used therapeutically. In practice, however, the use of radium and similar elements is reserved for cancerous and similar growths. Radium is a rare commodity while X-rays are readily available as required where there is the proper equipment. Hence it is natural that the sparse quantities of radium available should be reserved for the more serious cases that will not yield to other treatments.

The chief interest in practical therapy with radium is that there are three methods of administration. The radium may be brought within a suitable distance of the patient and the appropriate part irradiated, much in the same way as the X-ray tube is brought near to the patient and focused on the required spot. Another method is to place the radioactive substance in contact with the body; this may be considered an extreme case of the first method already described. The third way is to introduce a supply of radium actually into the body, usually in a glass tube, so that even closer approach to the diseased part of the

body is made. In this last form, it is believed that the beta-particles are very effective. In the other two methods, the range is too long for the radioactive substances to develop their full potentialities. This method of introduction—the interstitial method, as it is called—also makes use of what is known as secondary emissions of electrons, due to the action of the original electrons and radiation on the filters in which the radioactive charge is placed.

Radium and some of the other radioactive substances of the thorium series have shown themselves more successful in conditions of excessive white blood corpuscles than X-rays, and have been used where the latter have failed. In these cases, the charge is introduced into the body so as to gain the full effect of radiation, including, it is probable, some of the other ineffective power of the alpha-particles.

There is a curiously selective effect in these treatments. Radiothorium is shown to have a bigger influence on the liver and spleen than either thorium X or radium, both of which appear to exert their radiation chiefly on the bone marrow. This looks as though a useful method of treatment was available, but this is not so, for if the substances are injected in the required manner, very dangerous after-effects result.

These ill-effects are known as radio intoxication, and the doses are cumulative in producing them. That is to say, each fresh dose adds to the previous intoxication and the case grows steadily worse. The whole body becomes, in effect, radioactive, and the destructive radiation begins to attack almost every part.

This destructive action is very similar to that produced by X-rays but it is much more intense, and the ulcers caused by it, if it is allowed to go unchecked in the earliest stages, are to all intents and purposes incurable. It was an effect unknown, of course, to the early experimenters,

and the classic case is that of M. Curie, who carried a sample of radium in his waistcoat pocket in order to be able to exhibit the new marvel to his friends. As a result, he developed very bad ulceration of the body, and this remained with him for the rest of his life, which was terminated tragically in an accident.

At one time, there was hope that complete success might be gained by the actual introduction of radium or some similar substance into the tumour or growth. Later experience damned these hopes, since there was no means of arresting the dangerous accumulation of radioactive deposits in the system. Destruction of the blood corpuscles follows in cases of advanced radioactive intoxication.

The affinity of these substances for the bone structures has been demonstrated by a very curious experiment. In this, a frog was killed by the injection of radioactive materials. Its body was then placed on a photographic plate, and a complete radiograph of the skeleton was obtained, showing that the bones themselves were so impregnated with the radioactive substances that they were themselves giving off radiation.

These methods of administering radium comprise what is now known as high-intensity radium therapy, but there is another, and now, perhaps, more widely used method known as the low-intensity radium therapy. This makes use of radon, the gaseous emanation of radium disintegration. Being a gas, the radon can be diluted by admixture with air, to any desired extent, and thus the intensity of the radiation can be controlled to a great degree. Radon baths and inhalations have proved successful to some extent, and this form of treatment may well be developed in the future.

This chapter has outlined those important methods of treatment, to the credit of which many striking successes stand, which have been in use long enough to have earned

the title of classical. They appeared at a very early stage in radioactive history, and the use of the substances did not wait for the development of the theory of radioactivity. Practice ran ahead of theory, but it was the advance of theory and the extension of knowledge of atomic properties that has brought the next stage of radium therapy—though radium therapy is not, for these, the correct term. The resources of the latest progress in atomic physics have been drawn upon to provide the doctor with some more powerful and, curiously, safer methods.

CHAPTER NINE

NEW WAYS IN RADIOACTIVITY

The alpha-particle emanation of radioactive substances is, generally speaking, useless in therapy. The particles have no great speed, on the scale of these things, though they are moving much faster than any high-speed aeroplane, and their penetrative power is low. They have an effect only in methods which actually introduce the radioactive substance into the affected tissue, and this, as we have seen, is attended by grave dangers, which, in modern practice, are looked upon with disfavour.

We may now recall something which was said in connection with atomic bombardments. In 1931, Chadwick announced the discovery of the neutron, a particle having the same mass as the proton, but possessing no electrical charge. By the aid of this particle, which can be accelerated as required, valuable new work was done. It can be given intense powers of penetration, since it is not retarded at any stage by the forces of electrical attraction which slow down charged particles like the proton, the electron, or the alpha-particle.

It was at once obvious that these particles could be utilized for medical purposes, and extensive experiments were carried out. These met with encouraging initial success. The neutrons appeared to have a very powerful effect on tissues, and their penetrative power was high. In the quality of the results, their effect was exactly

similar to that of X-rays, but they had a higher intensity of action. Comparison with X-rays has, indeed, shown that neutrons may have an effect twice as great under controlled similar conditions on normal tissues and as much as four or five times as great when tumours like cancerous growths are concerned.

Here seems to be a very powerful method of treatment that lifts radioactive therapy into new realms of certainty. One of the disadvantages of ordinary radium treatment is the uncertainty of the direction of radiation. The particles, for examples, may be ejected in any direction, and there is no known law for determining which way the next particle ejected will go. Mathematicians can base an argument on the theory of probability, but however elegant that may be (in their own language), for their purposes and for theoretical considerations, it is of no practical help in actual medical work.

Neutrons, on the other hand, can be directed more or less as required. Moreover, since they are themselves not charged, there should be no deleterious after-effects. The possibilities of this form of treatment are being actively explored, and it may well be that it will develop into something very useful and powerful.

But this is not the only way in which new physical concepts are helping forward the science of radiation treatment. In an earlier chapter, we glanced at transmutation experiments and showed that new isotopes of various elements were being produced by bombardment, and that some of these were unstable and radioactive. A further feature of most of these artificially radioactive substances is that they have a very short period of decay—in other words, a given mass soon becomes inert to all practical purposes, though theoretically a radioactive substance can never become totally inert and unstable.

Among the artificial radioactive substances produced

so far are phosphorus, sulphur, arsenic and sodium. It is the radioactive sodium which is of the most interest from the medical point of view.

Radiosodium is produced by bombarding ordinary sodium with deuterons—the nuclei of heavy hydrogen, the deuterons being accelerated in the cyclotron, a machine for producing extremely high voltages. The result of this bombardment is to transmute the ordinary sodium of atomic weight 23 to an isotope with atomic weight 24. After a little while this radiosodium reverts to magnesium, which has an atomic weight of 24 and a charge of 12, as compared with the 11 of sodium. In other words an electron is given off. The rate of ejection of electrons or beta-rays in the first experiments by Professor Lawrence of California, the pioneer of both these developments and the cyclotron, was as high as ten million per second, and he further states that this rate of emanation could be increased if greater voltages of bombardment were used in the transmutation.

With the greater radiation promised the radiosodium approximates in output to that of radium, but this is not the only aspect of the matter. Radium decays slowly; its life is about 2,000 years for the half period. Radiosodium half-life period is only 15 hours, which means that an equivalent number of atoms emits electrons much more rapidly. Hence, it is calculated that the activity of a sample of given weight of radiosodium is about a million times that of radium.

From the medical standpoint, these discoveries are of the utmost importance. In the first place, radiosodium gives a very great activity for a small weight. The dose required to attain a desired effect is very much smaller. But the rapid decay rate has a disadvantage as well in that it necessitates the use of very freshly prepared material, and not all hospitals have physical laboratories

containing cyclotrons attached to them. The future may see such a development. Against this must be set the most important fact of all—that which promises to revolutionize the whole technique of radioactive therapy.

Radiosodium reverts in a short time to magnesium. In this state all its activity has ceased. Moreover, magnesium is a salt quite harmless to the human body. Hence the great bugbear of radioactive therapy looks like having been overcome. The radiosodium can be introduced directly into the affected tissue and do its work. It is then dead, and the magnesium passes into the general system to be eliminated harmlessly in the usual way. There is no circulation of potentially dangerous radioactive residues through the blood stream and the alimentary tract.

This is indeed a very great advance, and it is by no means a mere vision. Radiosodium is already being employed with gratifying success in the United States, where special cyclotrons have been built for its production. It is to be hoped that similar facilities may be available without undue delay in this country. The advantage of being able to use a substance that need not be recovered is too obvious to need stressing, and it is likely that, if this technique is developed and its availability widened, great strides may be made in this form of therapy.

Here, then, are two striking ways in which atomic research is making available new means of healing and cure. On the one hand there is the possible use of neutron bombardment to produce with greater intensity and safety the results of X-ray and radium irradiation. On the other, there is the very powerful and practically successful use of artificial short-life radioactive substances, of which radiosodium is the chief. Nature pointed the way by disclosing the secret of radioactivity in radium. Man, with his indefatigable inquisitiveness, has found new ways of putting the natural processes to work.

But this is not the only beneficial result of atomic research in its applications to medicine. Another and very interesting use of radioactive isotopes of short life—again principally radiosodium—is to trace the progress of food through the body. With a diet is mixed a certain minute proportion of radiosodium or other substance. As the food makes its way along the alimentary tract, it gives out radiation, which can be detected by electrical means quite simply. Thus times can be determined, and in certain cases the position of obstructions can be accurately determined. In the end, the radiosodium becomes inert magnesium and it is finally eliminated without having caused any damage.

'Tagged atoms' is the name which has been applied to this method of observation, which has very great possibilities in diagnosis and ever greater ones in the experimental field, where it has, in fact, already been responsible for a fair amount of knowledge. It will yield much more in the years to come.

From the seemingly remote results of atomic research, therefore, medicine is deriving many new and powerful techniques or means of improving old ones. The use of artificially radioactive substances may not bring about the conquest of cancer by itself, but at any rate it does open up the prospect of more advanced and better treatments to add to those already existing—treatments that themselves are constantly being revised and improved. Moreover, the difficulty of supply of radium is overcome, at any rate to some extent.

Building a cyclotron for the purpose of transmutations is an expensive matter; but so is obtaining supplies of radium. And whereas a supply of radium is something that must constantly be augmented at every further outlay, a cyclotron is a machine that, once its capital cost is paid, will give results for a long period. So far as the

financial aspect is concerned, there is probably very little, in the present state of affairs, either way, though the cyclotron, as a producer, would seem the better investment. Moreover, radium is a dangerous material that has to be very carefully handled and stored under conditions of great rigour. Substances which decay rapidly need not be given so much attention—a great advantage from the practical point of view.

From Becquerel to Lawrence is a long step in knowledge, though in years it is only a short period in man's long history. But the benefits that have accrued from the study and elucidation of radioactivity are already considerable, and the way is now open for advances even more striking than those already made. Side by side with the atom bomb there are the creative uses of radioactivity. The particles which can blast and kill men are also those which can destroy malignant growths and cells. It is man who must decide the target and also which end is the more valuable to him. It is not often that the question of using a thing for good or ill is so clearly and decisively put, and it seems incredible that man should consider for a single moment that there is any alternative to the answer he must make.

CHAPTER TEN

DELAYED DEATH

At this point we may make a digression from the theme of the moment and go back to a consideration of the atomic bomb and its effects. One of the most striking and appalling features of the reports of its effects was the number of delayed casualties. Those who escaped the first awful cataclysm seemed in normal health; then days, or in some cases weeks, afterwards they suddenly became ill and in a short time the death they believed they had escaped overtook them.

There has been much speculation on these deaths, which are believed to run into thousands, but after what has been said in the previous chapter, their cause should be plain.

When the atomic bombs fell on Japan, immense stores of radioactive energy were released. Much of it was dissipated in the terrible destruction of the explosion. The energy of release was used to liquidate—to use a fashionable term—everything in its path. Human beings, animals, buildings, vegetation—all were swept away. But some of this energy must have remained. Human beings were subjected to intense bombardment by radioaction of various kinds—exactly the same kinds as those which come from radium and similar substances.

The delayed deaths, therefore, were due to precisely the same kind of radioactive poisoning as has already been mentioned. These poisons attack the blood-producing

centres of the body—the bone marrow, the spleen, and the liver, amongst others. The white corpuscles are destroyed and then the red, and the life stream of the body is rendered useless.

It is reported that deaths of this kind occurred at great distances from the actual explosion, and it is surmised that dust may have been carried by the wind, that water supplies may have been contaminated, or it is even conceivable that the intense atomic disturbances may have engendered the dissolution of other matter not normally radioactive.

As this is being written, a full medical and technical report is not available, but what has been reported on good testimony is sufficiently alarming. It shows with what dangerous weapons man is playing when he turns his hard-won knowledge of the structure of matter to destructive uses. The effort to produce an even more terrible explosion and consequent destruction in war is, of course, natural, and must be accepted for as long as the human race feels that war is inevitable and unavoidable. But the secondary consequences of this newest form of destruction may well prove even more disastrous than the primary ones.

No-one can say, in theory, for how long this kind of delayed death may persist. People directly influenced by the radioactive discharge would take time to develop the symptoms of poisoning. But the important point from the medical and humanitarian point of view is, whether the explosion is the end of the matter or whether it sets loose radioactive forces that persist for a considerable time and in sufficient quantities to be a continued source of suffering.

The atomic bomb, it is stated, derives its energy from the disintegration of uranium. But uranium is the element with the longest half-life period of all. A little of it may

linger for a long time in unsuspected places and be the cause of contaminated wells and springs for example, or it may cause green vegetation on which domestic animals browse, to be a source of disease and death to them.

There is the further point that transmutation experiments have revealed the possibility of creating radioactive isotopes of substances that do not normally show any evidence of atomic disintegration; the case of radiosodium has been discussed at some length. It is not at all unlikely that the severe bombardment to which the very rocks and soil were submitted by the explosion may have caused certain of their constituents to become radioactive, and thus be an additional productive centre of human disorders.

These are questions which, in the interests of the world at large, as well as of those on the spot—and these latter include not only Japanese but members of the occupying forces—should be subjected to the most searching scientific investigation. Though in the existing circumstances, the task must be a grim one, it might well be that valuable lessons of the greatest importance to scientific research are available here.

It is an interesting problem whether this new method of releasing nuclear energy has any direct value to medicine, and particularly to the types of therapy that have just been discussed. The question seems to pivot on the question of control, which will be the subject of more detailed consideration later on. Here it is sufficient to say that the difficulty in medical application of radioactivity is to limit its range and focus its direction. The explosive release of greater energy than radium or radiosodium can give, does not, in the existing state of knowledge, appear to be desirable. But no-one can forecast the direction in which these gigantic experiments may lead us.

The point that it is desired to bring out in this brief digression is that the best possible use for the benefit of man must be made of whatever can be learnt from the dropping of the atomic bomb. Radioactivity has already shown itself to be a powerful weapon in the fight against disease, and often the pointers to its employment in this fight have been the accidental production of diseased conditions in the bodies of research workers. The remains of Hiroshima and Nagasaki may have lessons of the same kind to teach on a scale more gigantic than any hitherto imaginable. By learning them, by extracting the last ounce from their teaching, good may eventually come of evil, and the achievements of man's mind turned to more productive use.

CHAPTER ELEVEN

MINOR BOONS

X-ray and radioactive therapy are the chief contributions that atomic research has made to medicine, but there are other ways in which the art of healing stands in debt to this, the youngest and most fundamental of the sciences. They are many. Indeed, just as in one form or another physics gives its quota to almost every aspect of civilized life, so it is almost impossible to list all the many advances in medicine due to the same knowledge.

The thermionic valve has found its place in medical science no less than in so many other human activities. It has provided a means of enabling the deaf to hear better by means of small amplifying sets and it has also been employed in making an artificial voice for those war casualties who have lost the use of their larynx. In this case the microphone is attached to the neck and the voice is amplified through a small, portable loud speaker.

In diagnosis, electrical devices play an increasingly important part, and in many of these the valve finds a place. It has been said that the judgement of the doctor is today being replaced by mechanical records. That is not a very big exaggeration. It is all to the good that reliance can now be placed on exact knowledge rather than on the tricky interpretation of data, the very nature of which can be assessed only by an individual skill.

There are types of radiation treatment other than the two principal kinds to which some space has been devoted. Various forms of light radiations are in use, and though these have no immediate connection with atomic research, the fact remains that that branch of science has solved many problems to do with light in recent years and so has made the approach to light therapy more scientific and less dependent upon purely empirical knowledge.

This is particularly true of the effects of ultra-violet light, which is that light immediately below visible light as regards wavelength—that is to say, its wavelength is only slightly shorter than that of the shortest waves that are capable of being perceived by the eye. In this work, the concepts of the quantum theory, which is too technical to consider here, have been very helpful, and what was previously purely experimental knowledge gained by experiments has been placed more firmly on a foundation of recognized theory. The quantum theory is an integral part of modern atomic theory, and the present-day models of the atom are based upon it. Briefly, it lays down that energy is given out in little packets, as it were, known as quanta, though these are not atomic in the sense of being invariably the same. Some of the effects of ultra-violet radiation can, in fact, only be understood when the one-time universal wave theory of light is discarded in favour of the alternative and more modern theory of photons or light particles which, in a sense, bombard the body. It is these which cause the so-called photochemical effect—the power of light to excite certain substances. It appears that ultra-violet light has the same influence, in certain conditions, on the skin and the immediately underlying structures, as well as on the general state of bodily health. Ultra-violet light has proved valuable, too, in the treatment of rickets.

These brief details are given for the simple purpose of completing the picture of the range of radiation and other treatments available to modern medicine. They are not more fully discussed for the reason that they are not directly the outcome of modern atomic theory, and therefore do not have an immediate bearing on the main theme of this book. But they are useful makeweights in the evidence for the benefits which atomic research has conferred on humanity. It is not surprising that there is scarcely a sphere in which the influence of these theories cannot be traced, since physics is concerned in this aspect with the very bases of matter and energy, which make up the whole of the universe. It would be strange indeed, and, in fact, a complete disproof of the whole of modern assumptions in atomic physics if medicine were not affected by discoveries in the constitution and behaviour of matter.

CHAPTER TWELVE

THE ATOM AND HEREDITY

One of the long-standing puzzles of animal life has been the question of heredity, not least in human beings. Why and how is it that the qualities, good and bad, of parents are transmitted in some degree to their offspring—and even more surprising, how does it come about that some children are born with characters that seem not to resemble in the least degree those of their undoubted parents?

There is nothing more bewildering than the changes which can take place in a single generation. The parents of high talent may have a child of low intelligence, while parents of average abilities may, on the other hand, have offspring of outstanding genius. There is no record, for example, that the parents of either Shakespeare or Beethoven, to quote only two examples, were notable in any particular way, yet each of these was a giant in his own particular sphere.

Modern genetics—the study of heredity and its transmission—has thrown some light on the mechanism by which characters are transmitted from generation to generation. It is a complicated and still somewhat uncertain science, for though it has made some remarkable discoveries, it has also failed in other directions to throw any new light whatsoever on long-standing problems. But its triumphs have been chiefly, as has been said, in the mechanism of the transmission. Its findings are mainly in

the field of how, not in the more fundamental sphere of why.

In modern theory, hereditary characters are transmitted from parents to offspring through the media of genes, which are largely hypothetical points in the chromosomes, the long rod-like structures that form part of the male and female reproductive cells. These are capable of combining according to defined laws, into which it is unnecessary here to go very deeply. It may be said, however, that each gene is supposed to be associated with one particular characteristic or group of characteristics, such as eye colour, and that there are dominant and recessive forms. The father and mother each supply one gene of each kind. If, of these two, one is dominant and the other recessive, the observed characteristic—as, again, eye colour—is that of the dominant form, but the recessive character is latent in the individual and may be transmitted by him. Thus, a brown-eyed man can have the dominant gene for brown eyes and the recessive gene for blue eyes, or two dominant brown-eye genes, and his children may, therefore, be either brown-eyed or blue-eyed. But if he is blue-eyed he must have two recessive genes (otherwise the dominant one would mask the recessive one), and if his wife is also blue-eyed, all their children must have the same eye colour.

This is the general theory, very broadly stated, and in practice it is subject to many modifications and variations. But in spite of these carefully worked-out laws, derived largely through experiments on fast-breeding insects, notably the banana fly, the fact remains that many almost incredible exceptions occur in normal life. These are ascribed to mutations, as they are called—the spontaneous alteration of the character of genes. It is as though some force comes into play to transform the genes so that they produce something which is not in the heredity of either

parent. Some biologists see in this process an explanation of the changes that occur in evolution.

All manner of theories have been advanced to cover this idea of mutations, but it was not until atomic physics placed new experimental weapons in the hands of the geneticists, as of others, that any real progress was made. The results have been rather astonishing and have given a new turn of thought to genetic theory, causing it to modify to a large extent some of the earlier ideas that had been accepted as unalterably based.

The major discovery has been that these genes are highly susceptible to various kinds of radiation, particularly those of short wavelength. Under exposure to such radiations they mutate, or change their character, in a very remarkable way. Moreover, it has been found possible to exercise a certain amount of control over the process by varying the length of exposure and the intensity of the radiation.

In this work X-rays have been chiefly employed, and the experimental creatures have been the quick-breeding drosophila fly, the genetics of which are now very completely worked out. But similar results have been obtained with neutron bombardment in more recent research, from which it would appear that the genes react to bombardment rather than to pure influence of radiation as such. The suggestion has, in fact, been made that the genes are atomic or molecular in character, and that the bombardment has the usual effect of altering their structure.

Moreover, radiation of this kind has modifying effects on the unborn young, whether it be an embryo in a womb or one in an egg. On the fly eggs, neutron bombardments have produced quite unexpected changes, and the total effect of such bombardments is stated to be twice as high as that of X-rays of similar power measured by the ability of ionize (remove free electrons) the air.

In the human being, irradiation with X-rays in the early stages of pregnancy leads to abortion, and at later stages results in serious damage to the unborn child. Monsters have been accidentally produced when the mother has been subjected to X-ray treatment during her pregnancy, and the nervous system is invariably affected to a marked degree. A curious suggestion made by the results so far known is that the male embryo is more susceptible to the rays than the female.

These results are the natural outcome of the known effects of X-ray and similar radiation. The cell life of the growing organism is thrown out of balance and in many cases is completely arrested.

Though these experimental results are of very great interest, it may be asked whether they give any clue to the curious mutations that occur not merely in fruit flies but also in so highly complex a creature as man? There is an answer to this question, though at present only a tentative one; and it leads us again into the sphere of atomic physics, though into a region we have hitherto not explored.

Experiments in atomic physics revealed, comparatively recently, the existence of a hitherto unknown form of radiation to which, because it seemed to have its origin in interstellar space, the name 'cosmic rays' was given. It was in the investigation of these rays that the positron, the particle equal in mass to the electron but of positive electrical charge, was discovered—the same particle that later was to make its appearance in connection with transmutation experiments by bombardment.

These rays have an exceptionally short wavelength, far shorter than that of even the gamma rays, which up to this time had been regarded as the shortest naturally occurring radiation. They have extraordinary penetrative power. Experiments have detected them deep in the earth

and on the floors of great lakes. They seem to beat down mercilessly from the depths of space and to pass through everything on earth, so that unknown to ourselves we are constantly being bombarded by them.

With the known effects of very short wave radiation on the human body, it was highly probable that this intense and continuous radiation might be productive of cellular change. At the moment this is little more than a suggestion, but it certainly lies within the bounds of high probability. There is no reason to suppose that the human body should be immune to this, the most penetrating of all radiation, if it shows such marked reaction to less powerful rays.

From this idea has come the further suggestion that it is these rays which may provide the natural basis for mutations—that through them Nature produces similar results to those which man has obtained in the laboratory by the use of X-rays and neutrons. The theory, if it can be dignified by such a name, is an interesting and attractive one but it needs much more evidence before it can be even provisionally accepted.

It has been pointed out that the major effects of irradiation by artificial means are fatal, or at any rate extremely harmful, to offspring. This is in accord with the results of the study of natural mutations in nature. The general principle is that a mutation or sport is usually harmful to the species or fatal to its individual continuance. The normal pattern of the particular species tends to exist, and it is only occasionally that a mutation produces a type that is superior to the normal. It is these rare types that give the stimulus to the evolutionary process, since, as the change occurs in the genes, it can be transmitted. The cosmic rays may, therefore, be the prime mover of evolution and responsible for the ceaseless variation of the forms of life on this planet.

Though the experimental evidence is largely to seek and would obviously be extremely difficult if not impossible to obtain, the theory holds together—as a pure speculation. The cosmic rays would induce changes only according to the laws of chance, and therefore it would be more likely that a mutation would be harmful than beneficial. But there is nothing in the process to make a harmful result, as such, more likely than a beneficial one, hence occasionally the latter would occur.

The genetics of man are extremely complicated and evidence is very hard to obtain. For one thing, experiments on man are not readily made; he cannot be used, on a large scale, as a laboratory guinea-pig or rat. Furthermore, he is slow-breeding, and the usual allocation is three generations to a century. A hundred years of work in the most favourable circumstances could yield little conclusive material—very different from that obtainable from certain insects, which can be induced to produce a hundred generations or more in the course of a single year. While, therefore, the genetic constitution of a quick-breeding strain, even of so relatively high an animal as a dog or cat, can be more or less fully known, that of man is very difficult to unravel, and mutations in him may not be mutations at all, but the appearance of recessive qualities hitherto masked in successive generations.

The effects of cosmic rays, if there be any, are therefore unknown on man, and experiments will have to be conducted on other animals and the results transferred by analogy to man, with results that cannot, in the very best conditions, be anything but inconclusive.

Here, then, in one of the fundamental fields of biology—and therefore close to medicine and the welfare of man—the hand of atomic physics is to be seen. It is known that his heredity and his offspring can be affected by radiation, especially that of the elemental particles of

matter and energy; and it is possible that all the time changes in him may be going on under the stimulus of cosmic rays, the very nature of which is as yet barely understood. The interdependence of the whole universe, from stars to the simplest form of terrestrial life, is nowhere more strikingly demonstrated.

CHAPTER THIRTEEN

CHEMICAL FOUNDATIONS

All science has been profoundly modified by the trend of thought in the past half century and the influence of atomic theory has been felt in every branch. New discoveries have outmoded former ideas and many hitherto almost sacred conventions have been swept aside. During the nineteenth century it was the accepted conception that the human body behaved as a highly complex self-repairing heat engine. It was a mechanistic age dominated by the steam engine and the thought of the animal's system in that way was perfectly natural. Research, however, gradually showed that idea to be erroneous. It did not describe enough of the working of the bodily complex, and new discoveries, particularly of the deep effect of such small things as micro-organisms, vitamins, and viruses called for a new and more complete picture.

Thus it is that today the body is looked upon rather as a very involved chemical system whose parts are closely interrelated, yet some of which are quite capable of working in isolation. It is true that the heat engine theory is useful for some purposes, but it explains only part of the system, and that not completely. The classical example of its breakdown is the evidence provided by vitamins or accessory food factors as they were first known. It was found that animals could be fed on a diet that afforded them all the heat, or energy, units they needed—and yet

failed to attain a state of healthy living; but when certain substances, now known as vitamins, were added, full health was restored. Obviously the body needed something other than mere energy put into it. What it requires are substances that help to keep the very delicate chemical processes of the system in a perfect state of balance.

Since the commencement of the present century, the subject of biochemistry—the chemistry of living processes and tissues—has made great strides, and much more is known today of the chemical mechanism of the body than ever before. It has been found that many of the actions formerly thought to be physical now have a chemical basis in the body, and it has been found possible to produce, outside the body, some of the substances made by the various organs, thus permitting deeper study and understanding.

This work, which calls for a patient and very subtle technique, has been accelerated by the progress made in general chemistry. New methods and new theories have stimulated practical progress and widened the field of accepted theory. In turn, general chemistry has advanced because atomic research has given it new weapons and amplified underlying theory so that much of what was formerly merely practical knowledge can now be explained in terms of universally accepted theory.

Here we are back again to the fundamental nature of atomic research. Chemistry, as we have seen, is concerned only with the energy levels associated with the more or less loosely attached orbital electrons of the atom. By chemical means these can be detached or rearranged, and various methods of combination are possible. Though most of these reactions have been known for some time—and some of them, particularly in organic chemistry, are very complicated—there was, until comparatively recently, no unifying principle. Atomic theory has provided

that theory and enabled much to be understood that was hitherto obscure.

In the chemical field, however, atomic theory has not merely been able to describe what goes on; it has given knowledge from which the probable behaviour of unknown compounds might be deduced. This is a very great advance. The chemist no longer proceeds by the tiresome process of trial and error in all cases. He can, in many instances, predict how substances will behave and deliberately set out to make those in the laboratory.

Naturally this has had valuable repercussions on medicine. Indirectly these stand to the credit of atomic theory in the service of health. Drugs working through chemical action on the body are among the very oldest forms of treatment, though in the old days the most fantastic ideas were common and not very many of the old medicaments survive. Even so, it is noteworthy, in passing, that some of the drugs in successful use today were known and employed by the ancient peoples, whose instinct in these cases seems to have been unerring.

The new approach to chemistry through the science of physical chemistry which, it might be said, bridges the gaps between physics and chemistry, has brought new light to the chemical side of medicine. The action of drugs in common use has come to be more fully understood and certain new ones have been introduced. The rapid progress in pharmacology is, in fact, so rapid that it is difficult to keep pace with it, and the range available for treatment is so wide and ever widening that the problem of prescribing the right one for use in any particular case is becoming almost a specialist job.

Another illustration of the constant interaction of various branches in modern science is provided by the effects of X-ray research in the pharmacological side of medicine.

It was through X-rays, in the hands of the physicist, that the nature of crystals and their methods of construction were elucidated—X-rays whose first practical use had been in purely medical work. This new crystallography led to marked progress in chemistry and the production of many new substances. In turn some of these new substances have proved of great value in medicine. Each science gives something to the other, which very often returns the gift with added interest. The integration of the sciences in this way is one of the most significant developments of the times.

In some ways, the virus can claim to be the most astonishing discovery in the field of biology for a very long time. This minute body, far too small to be seen through even the most powerful microscope and so small that it cannot be stopped by the finest filters, is known to be responsible for causing a number of diseases both of the human being and of plants and animals. It is suspected that it is at the root of other troubles, among them the common cold, but its great minuteness makes it extremely difficult to detect.

The virus is a deep mystery. It seems to be about the size of an average molecule, but whether it is a simple chemical molecule or whether it is a living thing cannot be decided on the evidence so far collected. It appears to have a dual character in that sometimes it behaves as though it were a chemical entity working through association with other molecules and inducing reactions in the normal way, while at others, and nowhere more strikingly than in its powers of reproduction, it has many of the properties usually associated with life.

Some workers see in the virus the link between the living and the non-living, the bridge that so many have sought throughout the centuries. They fit it into a theory that also claims to observe in crystal growth some of the charac-

teristics of life. This is highly speculative, but it is worth noting in passing.

The virus, interesting in itself, is of special importance here as it provides examples of the way in which atomic knowledge is helping mankind in his struggle for healthy existence. Since it is at least molecular if not atomic, it is subject to the effects of irradiation, and it is thought by many that in the end the most effective way of virus control will be to deal with the germ through radiant means. Radiation with its dual effect on chemical properties and life would in fact, superficially at least appear to be ideal.

But the great problem today is not so much dealing with the virus, for where it has been isolated as the causation of diseased conditions, effective methods of treatment have in most cases been evolved, as in detecting it and studying its methods of working. For reasons of size it is not only beyond the reach of the ordinary optical microscope but theoretically impossible to see by ordinary means. This is because its size is less than the shortest wavelength of light. Any object as small as this cannot reflect incident light rays and so cannot be seen. Objects just below the shortest visible wavelength can be photographed by means of ultra-violet light and so made visible, but this method is, again, not applicable to many viruses because of the extremely small diameter.

Recently, however, atomic research has placed a new and very powerful means of observation in the hands of the experimenter. This is the electron microscope. In this a beam of electrons is projected in much the same way as a beam of light, and it is focused not by lenses such as are used in the ordinary microscope but by a roughly similar arrangement of electromagnets and electrical fields.

Now the electron, when regarded, as it can be, as a wave motion, has an extremely small wavelength and it

can be reflected by objects it strikes in the same way as light is by more massive things. Thus a pattern is obtained, and this pattern can be photographed on a plate or film. It is claimed that by the aid of this instrument not only objects of molecular size but also atoms themselves can be photographed for study.

This instrument should prove of the utmost use in virus research. The virus is a most important thing in causing disease and in the processes of biochemistry is now generally admitted, and fuller knowledge of its ways on a big scale is necessary if virus diseases are to be conquered, and the causation of other conditions discovered. An apparatus that gives direct evidence of the behaviour of ultra-small bodies of this kind is precisely what is needed in this research. Since the virus is regarded as mainly chemical in its action, the work comes back to medicine through the medium of chemistry, and thus, both directly and indirectly, atomic research makes a fresh contribution to the science of healing. The first electron microscope was designed and used in the United States, where the most encouraging results have been obtained. It should become in the next few years a standard instrument of research not only into viruses but also into all cellular and atomic changes, which stand at the root of all living processes.

In the production of new and powerful drugs and medicaments, in the elucidation of the workings of known substances, and in studying the chemical processes of life, atomic physics is speeding up progress and replacing doubt and assumption by certainty. It may truly be said that to take away modern atomic theory would be to knock out the bottom of the whole of modern medical as of general science.

CHAPTER FOURTEEN

THE ATOM ON TRIAL

With a brief glance at the chemical aspect of the subject, our list of the achievements and contributions of atomic theory to the art of healing must be brought to a close. It is a catalogue that could be almost indefinitely extended, for ever new applications and discoveries are coming to light, and the more atomic research gives us fundamental knowledge the clearer our ideas, even of the most familiar processes, become.

This book started out to show that despite the ravages caused by the atomic bomb, atomic research had conferred great benefits on the world, and that there was no need to fill in the credit side of the ledger with entries based on nothing more solid than possible applications of nuclear energy to useful purposes. In effect, the atom was put on trial. Little has been said here of the case for the prosecution, the case that atomic knowledge has proved a curse to mankind. These pages have been concerned, however inadequately, with assembling some of the evidence for the defence. But it is not their purpose to act for one side only—to present, in other words, a biased case, which is both unscientific and needless. Rather it is the intention to make available facts on which the reader may form his own independent judgement.

This is important, for in the long run it is the ordinary man in the street whose word must be heard on this all-important subject. It is for him to say, in the last resort,

for what purposes public money shall be spent and to decide whether scientific knowledge is to be used for good or ill. A firmly based public opinion can force the hands of governments and bring about results that may seem at first to be unattainable.

In these concluding chapters, therefore, we propose to put the atom more formally on trial in the form of imaginary speeches for the prosecution and the defence and in a short summing up, with a brief glance at the future.

A lot has been said here of theoretical and technical problems, an understanding of which is necessary if the full extent and importance of the subject are to be grasped. But it must not be thought that the last word has been said. On the contrary, nothing more than a bare outline has been given. Those who wish to go deeper into a subject that is fascinating and ever fresh will find there is ample literature available ranging from the very popular (which is often misleading) to the highly technical. The point it is desired to make here is that there is nothing mysterious or formidable about atomic research. Its lessons can and must be grasped by all, and it is hoped that this little book has contributed something to that understanding.

With this we may pass on to the trial of the atom. The indictment has been read. It is that half a century of atomic discovery and prying into the structure of matter and energy have led to the means of destroying mankind without any compensating benefit. The case has been presented at times hysterically with much publicity recently, so there is no need to go into it in detail here. It is based entirely on the results of the atomic bomb explosions in Japan and the tales of devastation and suffering to which they have given rise.

For the defence it is claimed that atomic research is not merely capable of conferring great benefits on mankind

in the future but has in the fifty years it has been going forward in its modern form already done a very great deal to alleviate man's distress. The concrete evidence of this has been outlined, very baldly, in the foregoing pages, where also evidence of the character of the atom and its constituents, the subatomic particles, has been brought forward. This is important for it is sought to show that there is nothing inherently evil in matter. Like all things in Nature it is neutral, and it is man's use of them which makes them good or bad.

The stage is, therefore, set for the final phases. The case for the prosecution, the closing speech of the prosecuting counsel, will be given first, since the atom itself has not been put into the dock and the Crown is not prosecuting. The jury must be the wide public of the world. The judge is destiny itself.

CHAPTER FIFTEEN

FOR THE PROSECUTION

The case against the atom, members of the jury, is that it is a highly destructive and evil entity and that its activities, which are cloaked in a certain amount of highly suspicious mystery, are a direct menace to the future existence and happiness of the human race. It is contended by the prosecution that the atom is by all civilized standards uncontrollable, and that while it can wreak very great havoc, it is impossible to use it for good and worthy ends.

The evidence on which this case rests has been clearly given. There is no-one today who is not aware of it. After fifty years of research work in which some of the finest brains in all countries have been engaged, the sum result is devastation on a scale hitherto associated only with great natural calamities such as earthquakes or tidal waves.

It is true that these results were attained in war when the powers of destruction are paramount. But that does not alter the nature of the case. As the result of forced progress, the atom has been forced to reveal its true character and to stand out before all men as a slayer and destroyer of the worst possible kind.

Everyone is familiar with what has happened in Japan. It may be claimed that the complete details are not yet available. That is true. But fresh data are repeatedly being published, and each fresh batch adds some new horror

to the total story. At first, when the bombs had been dropped on the Japanese towns, the tales were of widespread destruction both of property and of human life. There was destruction and massacre on a scale never before attained by man. The slaughterings of Genghis Khan, of Attila, of all the most bloodthirsty leaders of history, seem almost ridiculous by the side of the damage and death brought about by two small bombs which, we have been told, were no larger than a rugby football. And it is stated that these two bombs, each of a different type, are but the precursors of other and still more deadly bombs—bombs that will produce cataclysms even more terrible than those with which the world has recently been confronted.

This is not all the story. More reports came in and fresh horrors stood revealed. Not only did these bombs kill and destroy with an efficiency far beyond that attained by ordinary high explosives which make use of chemical reactions. They seemed to have very terrible chemical effects as well. People who had survived the force of the explosions were suddenly taken ill and died in great agony. The death roll continued to mount weeks after the bombs had been dropped. In the atom bomb, the war of explosives and chemical warfare had become inextricably mixed. The dangers of explosion had been multiplied hundreds, perhaps thousands, of times; to them had been added all the terrors of a subtle poison gas which struck at the very essentials of the human system. It may be that water wells have been contaminated, the very earth made a source of injury and pain and death. But the evidence for this is not complete; and indeed it is not really material, for the evidence available in other directions is damning and direct enough to command a sure conviction.

The way in which these gigantic effects are produced is not really of importance to the indictment, though the defence has put in an elaborate explanation of them. The

jury is concerned not so much with the way in which violence is done as its results. It does not matter if a common ruffian makes use of a stick or a rubber truncheon; it is the fact of his having committed assault that is the charge on which he is indicted. So with the atomic bomb. It does not matter that it is nuclear energy which is employed. If ordinary chemical explosives had produced the same effects, a charge would lie. But it may be pointed out as highly relevant that these effects are particularly the property of the atom. They are inherent in its very nature, and it may seem to you that, in bringing forward evidence of the nature of the atom, the defence in its zeal has proved rather too much for its own purposes.

It has been established on scientific grounds that can hardly be disputed by the layman, that the atom contains within its central part or nucleus vast stores of energy on a scale not otherwise available on earth. It has been further demonstrated on the same authority that this energy is, even in Nature, subject to violent release, as in radioactivity, and that that release is beyond the power of man to control under normal circumstances. These hardly seem facts on which to base a claim for the innocuous nature of the atom. They go rather to uphold the contention of the prosecution that the atom is inherently dangerous and uncontrollable, a force for destruction in the world.

There is no need to linger over this point except perhaps to bring out what happens when these bombs explode. The forces released are of the same kind as those which give the sun its powers to warm the earth and bring life into being. It is stated that at Hiroshima and Nagasaki temperatures of millions of degrees, far too great for us to realize here, were created. These are the temperatures of the sun. But at a distance of ninety-three million miles their effects are moderated to a degree that makes them

bearable by man. Near to us on earth they are the forces that disrupt the universe. The evil predominates over whatever good there may be in them.

It is another contention of the defence, as brought out in evidence, that atomic research has yielded good results in its fifty years of life, that it has alleviated human suffering, conquered disease, held death at bay, by its applications in the hands of the medical profession.

This is a bold, perhaps extravagant claim. It is based on the results of treatment of certain conditions by X-rays and radioactive substances. True it may be that some benefits have been gained by these means, but there are substantial modifying factors which make the picture less attractive than the defence would have us believe.

The defence has not sought to deny—how could it?—that at every stage there have been difficulties and dangers in these treatments. One of the discoverers of radium itself, M. Curie, carried with him to the grave an abdominal ulcer that had been caused by radium. Not a few research workers have died or suffered horribly through the burning and destructive effects of radiation on their bodies. Some patients, too, going in search of relief from pain and disease have found only something more terrible than that they wished to have cured.

X-rays have, indeed, proved a powerful weapon in the armoury of medicine, particularly in diagnosis. But this treatment is not on all fours with the energy of the atomic bomb. X-rays are under control because they do not make use of energy released from the nucleus itself. Even so, there have been troubles and suffering enough from the use of X-rays.

In radioactivity the same kind of energy as that employed in the atomic bomb is present. But its claims in medicine are perhaps not so high as might be thought. It is true that it can destroy or remove cancers and other

growths given suitable conditions, but only by taking risks of a kind for which, even today, there is not full protection. If the substances are introduced into the body so that they produce their full effect they set in train subsidiary processes that may lead to complete poisoning and death. One may well wonder if the results attained are worth the cost. The atom releases its energy, it seems, only to make good its power to destroy.

Medical men themselves are by no means agreed on the value of radioactive treatment and in many cases in which it has been successful, results at least as good could have been secured by the surer and safer method of surgical operation.

As for the applications of the branch of science known as electronics—applications of the thermionic valve familiar to us in our radio sets—little need be said. These devices are not the direct outcome of atomic research. They do not involve the release of nuclear energy. One may perhaps think they were intended as red herrings to confuse the trail, and it is well that this possibility should be borne in mind by those of you on whom the responsibility for arriving at a verdict rests.

What, then, is the true picture of the activity of this element of the universe, the atom? It is surely that it is a great and devastating power beyond the full control of man. He can release that power or energy, as he has done in these bombs, but only in such a way that it causes destruction. The energy comes out in a great wave. It cannot be turned on or off by the motion of a switch. And remember that the terrific explosions in Japan were the result of the release of atomic energy which, we have been told, was slowed down by all the means available to man.

Glowing pictures have been painted in public to show that, in time, this great energy may be harnessed as early

man harnessed the energy of the wind and water, and in modern times the energy of steam and oil have been brought under control. This is little more than speculation. Its realization is a dream that may never be fulfilled. The most optimistic of the propagandists of this belief point to a period of years measured in decades before this wonderful dénouement is to come.

Meanwhile, the destructive powers of the atomic bomb remain and will presumably be increased, because of the inveterate itch of science never to leave well—or ill—alone. That, at least, is a fact not resting on any bold assumption. It is something of which we have been reminded by the highest authorities.

A parallel has been drawn between the use of explosives in peace time production—in quarries and mines and civil engineering—and the possible applications of atomic energy. It is the contention of the prosecution that such parallels are, if not wholly false, at any rate not close enough to be a reliable guide. High explosives are chemical agents, and man has a very extensive knowledge of chemical processes. He has nothing approaching that knowledge of atomic processes, and every new step must be attended by dangers of the grossest kind.

Research will go on, we are told. Quite so. Science, we repeat, cannot leave well—or ill—alone. But what will happen in the research? Radium workers have been injured for life, scarred, burnt, and disfigured till death took them. Is it likely that further experiments in atomic energy on a large scale can be made without disaster? A whole township was created to make atomic bombs. What happens to that town if the almost inevitable accident occurs? Have we the right to condemn hundreds, perhaps thousands, of workers, citizens of the world, to dangers such as this? A single scientist, a small group of scientists, may take such risks on their own responsibility,

but virtually to force them on humble men and women as part of normal employment as a means of gaining a livelihood is surely asking too much. The mere idea stands condemned on every ethical ground, even in a world in which ethics seem to have lost their force as the result of dictatorships, wars, and anarchy.

The decision on the future rests with the men and women of the whole world. They alone have the power to arrest this evil before it has gone too far. They must not be bemused by mathematical jugglery and the glowing promises of men who, while they may be highly expert in evolving equations, are concerned primarily if not completely with their own work and play little part in practical affairs.

It may be that some of the promises they hold out have a basis of truth—that given this, that, or the other, they might be fulfilled. We might have a world in which abundant power was available on a scale never before known, and in which, accordingly, the need for human labour was almost non-existent. But is the price to be paid for this very hypothetical future worth while? Are we prepared to take the risks inevitable to its remotely possible achievement?

One thing stands out plainly above all else. The benefits of atomic energy in the future are prophecies—and man, for all his cleverness, has never made much of a success at prophecy, particularly in the scientific field. Against this is the very real and very terrible practical achievement of the atomic bomb. Our state of knowledge is very definitely that nuclear energy can kill and devastate and that the means exist of increasing that power. We have no clear knowledge or certainty that there is anything else in nuclear energy. We have promises and assurances. We have brilliant prophecies. It is only necessary to turn to the promises and hopes of the nineteenth

century to realize just how much those may be worth; and those old forecasts were based as securely on the science of their time as the prophecies of today are on the theories of the moment.

Members of the jury, the world has just emerged from a long and horrible war, the climax of which was reached by the dropping of atomic bombs. It was a war that had as its primary object the destruction of those nations which had a lust for power. That goal was gained. The hope of today is that something better and brighter may come out of the chaos and devastation which the war has left. It was a war, we were told, for freedom, a war to ensure lasting and inviolate peace for nations and individuals alike.

Let us be grateful that that war was won, and that the lust for world power was not gratified. But let us not overlook the fact that the lust for power may exist in other forms than the desire for conquest and the subjection of states and peoples.

Is the search for nuclear energy on this scale another manifestation of that lust? Is not man striving now to control Nature at its very fountain head? For what? That is the question. What good can the world derive from nuclear energy? Is it worth the cost, when we know that nuclear energy is the most destructive force man has ever played with?

That is the indictment against the atom. It may have powers for good on a very limited scale. But it has, indeed, immense powers for evil. The production of atomic bombs may be controlled internationally. It may be left, as it is at the moment, in the hands of one nation. But only for the time being. The secret cannot be forever held. And there may be other and simpler ways of approach so that the same or more deadly results can be attained by other means. It might be possible for a nation with evil intent

to make atomic bombs secretly, as Germany built up armaments in secret after the last war.

Perhaps this is the time for the world to make a great decision—one greater than it has ever been called upon to make before. Perhaps now the peoples of the world must cry aloud with one voice and say to science 'Enough! Cease this playing with the fundamental forces of the universe. We have already the means of producing as much as we want, of raising our standards of living higher than ever before, of abolishing alike poverty and starvation, of giving leisure and the full life to every one of us. Let us concentrate on utilizing what we have rather than seek new means. Perhaps the time will come, if we do that, when man will have grown wiser and kinder and his urge to destruction will have died. Perhaps man needs a spiritual change before he can command the ultimate. So now we declare that research on atoms must cease, that we know enough, and that science must realize its responsibilities. There must be no more Hiroshimas or Nagasakis. There must be no more wars.'

Yes, that is a tremendous decision to have to make. Yet the need for it is there. We have to choose now whether a certainty of destruction is worth balancing against a possibility of good, whether existing good is not enough to offset the problematical advantages of a hazy better.

The prosecution contends that that better is an illusion, that before it could be reached man would have forged the weapons for his own extinction. It holds that the atom is more evil than good, and that man has not and is not likely to have the means of fully controlling it. It is on that sober belief that we ask for the condemnation of the atom, the cessation of atomic research, and the complete destruction both of plants for the production of atomic bombs and of the knowledge that may lead to their creation.

CHAPTER SIXTEEN

FOR THE DEFENCE

The prosecution had built up a skilful case. On this showing, atomic knowledge stood condemned as a thing full of evil and the powers of destruction. It was something which was a curse to the world, from which everyone should shrink back in horror. The defence would have a hard task to make good even a plausible case in the face of this, the more so as the prosecution had seemed to meet all the arguments for the defence in advance.

That is often the way in trials. Each side seems utterly convincing until the other is stated, and a lot depends upon the final summing up by the unbiased judge.

And this is what the defence said in reply:

Members of the jury, the picture which the prosecution has put before you is indeed a frightening one. It is something from which you may, to use some words spoken by the prosecution, shrink back appalled. It is a vivid portrayal of destruction and death, of evil let loose in the world and on a gigantic scale. Let us say right at the outset that, if the atomic bomb was all that had to be considered, it is true enough. Indeed, perhaps if that were so the picture might be even more terrible. Perhaps the prosecution realized that this could not be, and by not giving the full details of world devastation by nuclear energy admitted implicitly that there was more to be said on the other side than it chose to admit.

The defence stands even more aghast at the horrors of Nagasaki and Hiroshima than the prosecution. For it sees in these disasters not the use of something fundamentally evil but the distortion by man's own wish of knowledge that could and will eventually confer untold benefits upon him. The prosecution has spoken of scientists as men who play little part in practical affairs, as though they were not all interested in the ends to which their work was put. Nothing could be further from the truth. Probably the people most horrified at the destruction in Japan are those who were most closely concerned with the development of the atomic bomb: the mathematicians whom the prosecution so despises, the physicists, the chemists, the engineers, and the rest. More than one has expressed his reluctance at being invited to take part in the work, knowing what the purpose was, however eager he was to take advantage of the immense opportunities for research made available to him. One well-known physicist who had done fundamental work in atomic research lost no time in making a disclaimer when his name was given as that of a participator and, in fact, he had taken no part in the work.

These are facts which should be publicly stated and stressed. Scientists are not men who take no thought of the results of their work in the practical field. They have complained bitterly time and again that their discoveries are prostituted to evil ends, and their plaints have grown in volume of recent years. They are at least as responsible members of the community as any other class. But they are, particularly in war, the servants of the people, as all other workers are. In war, it is the overriding needs of the State that claim first call on men's service. This applies to all. He has to give everything he has, whether it is skill or labour or money. He is forced to do tasks to which in peace time he would not willingly lend his aid. Is it contended that because millions of men were put into the

Forces and taught to shoot and bomb and kill that they are naturally murderers? Is fighting the chosen avocation of all in the army, the navy, and the air force, during these past six years? The idea is fantastic. But the needs of the State, of the world had to come first. The clerk became a professional killer. That is crudely put. It may shock many. But it is the truth. He did so not through choice but of necessity.

So with those who created the atom bomb. Better than any, they knew what they were doing. They realize far more than any of us who have not their specialized knowledge, the dire possibilities of nuclear energy when it is turned in destructive directions. If they made the bomb, it was not because they saw in it a golden goal towards which they had long been working. It was rather that they saw in its creation a necessity forced on them by events. It was a necessity for two reasons. If they did not produce a bomb quickly, the enemy might; and then the cause of the United Nations would inevitably fail. The second reason was that the bomb would shorten the war. It is true that thousands of Japanese died, and some, it may be, are still dying from the after-effects. But is it not also true that but for these two bombs the war in the Far East would still be in progress, and that many thousands more of allied soldiers, sailors, and airmen would have been killed? In that sense, the atom bomb has proved a life saver, and also it has released men who might have survived from the torture of jungle warfare where disease killed even more quickly and savagely than the Japs.

These are points that have been made before, but they are worth making again. They help to put the matter in its proper perspective and clear away the fog of revulsion which surrounds the news of the bombs themselves. The dropping of those bombs shocked, as it should do, all human sensibilities. The very natural reaction has been

'Away with it all'. It is nothing more or less than an elaboration of this attitude, which is based rather more on sentiment than on logic, that the prosecution has presented.

If the prosecution's case were carried to its logical end it would mean the banning of many of the familiar things of daily life, because they can be used for evil things as well as good. A knife can be used to kill a man; it is none the less essential to everyday life so that we can cut and prepare our food; in the hands of a surgeon it may save life and remove suffering, as it is doing dozens of times every day of the year in every country in the world. Shall we then, say, that knives must be banned—that fire must be banned?

Surely that is going too far. Yet that is what the prosecution says about the atomic bomb. It can kill and devastate. Therefore we must have no more of it. The prosecution dismisses the benefits of atomic knowledge airily as of little account and certainly nothing to set against the destructive powers in the balance of judgement. That is a one-sided view—a view appealing not to reason or justice but to sentiment alone. Sentiment is a bad guide in things of this kind. There must be a close assessment of relative values. That is essential. It is that which you, members of the jury, must provide in this case.

The prosecution has made great play with the fact that prophecies have been made about the future of atomic energy and has said they nearly always prove false in science. This is both true and not true. For while prophecies by scientists often err, they do so on the side of under-statement. Half a century ago, the scientific romance was very popular. Writers, leading among them H. G. Wells, endeavoured to portray the world as it might be. Many of their forecasts have come true—but with this

difference: that they matured much more rapidly than their makers imagined. Aeroplanes and wireless are with us now—and not in the twenty-first centuries as so many prophets said. So it is with atomic energy. It was forecast years ago, but no-one, even in 1939, would have said that it would be available practically in one particular form only six years or less later. If then one casts looks of suspicion on the confident prophecies of experts as to the ultimate utilization of nuclear energy for driving, say, our factories or generating power, let it be rather in the spirit of the sceptic who reads for their twenty years, ten years. History shows that science is usually far too modest in its claims.

It is true that the conditions of war accelerated the research which led to the release of nuclear energy, but there is a gain in that, however great the immediate destruction caused by the bombs has been. Much knowledge has been gained and more quickly than would otherwise be possible. The immediate goal was the atomic bomb, but the material for fresh advances has been assembled and the next and exciting task for science is to turn the data to practical account. It is something to which scientists will turn their attention enthusiastically and willingly. Perhaps some of them feel it is a debt they owe to the world to offset the shock that the bombs caused to world opinion.

The future of atomic energy is, it is true, not clear, but it is certainly clear how much progress has been made. The means of slowing the release of the energy has been found. The prosecution tried to belittle that, but it is a highly significant fact. There is every reason why that knowledge should lead to complete ultimate control.

To say that the atom is wholly evil is a gross misuse of words and a flat renunciation of all logical principles. How can an atom be anything but neutral in the sense of good or evil? Good and evil are human values—some

say divine. But they are certainly not attributes of matter, and atoms are the constituents of all matter.

An atom, or rather a fundamental particle, is simply something with mass and except in the case of the neutron and neutrino, as our evidence showed, an electric charge. Is there anything evil in mass as such, or electricity as such? Is the electricity which lights and heats our rooms, then, evil? Is the mass of our clothing and our houses a force of evil? Surely, again, the prosecution has overstepped the mark and gone into the most absurd of extremes.

Once again it must be pointed out that scientific knowledge cannot be either good or evil. Its uses may be at man's discretion. Poisons may be also healing drugs. Fire may burn or bring the inanimate back to life. There are two sides to everything, an antithesis that must never be forgotten. It is for man to resolve that antithesis without fear.

For it is fear that stands at the root of the outcry against the atom and atomic research. Fear of immediate consequences. Yet man has risen from the lower levels of creation simply because he had the type of mind that was prepared to see a risk and take it if he thought that something good would come of it. No doubt to primeval man, fire was as deadly and uncontrollable a thing as atomic energy seems to us at this stage. But he did not abandon fire. If it set the forests alight, it also warmed his cave and cooked his food. So man got control of fire; and from that have come most of the useful arts and crafts.

To say that there is only explosive force in the atom or its nucleus is also ridiculous. The force is certainly explosive—we have all too much evidence of that. But then so is steam in the boiler of an engine. Many modern boilers work at immense pressures, sometimes a thousand

pounds or more per square inch. Man controls these pressures and they do useful work in the steam engine. The analogy applies to the atom. Here is energy locked up like high-pressure steam in a boiler. It can be used for explosive purposes, but also man can and will devise systems of valves and controls so that the energy can be released in an orderly way and do useful, controllable work for him in his factories, his homes, and his streets.

The view of the prosecution is not only misguided; it is also one-sided. It speaks as if the whole achievement of half a century of brilliant research is the potential destruction of man. This is surely the imagination of a sensational novelist, rather than the considered statement of a reasonable man. Those fifty years have been a half century of remarkable achievement in the practical no less than the theoretical side. They are the summation of man's long struggle to gain complete control over his environment and the forces of Nature. And now, when he stands on the very threshold of success, the prosecution would say 'So far and no farther. All the previous risks were worth while but this one is not'. He would make the whole tribe of Israel the same as Moses and deny it entry into the Promised Land.

It will be our duty a little later to review the very positive evidence we have brought forward to show what the achievements of the atom are—and that only in one field, the field of medicine and healing. For the moment we must take another point of the prosecution and show it to be the false assumption that it is.

The prosecution urges that there should be no more atomic research. It says that there is enough power and potentialities for good in the world for everyone to have enough and to spare. That is to some extent true, though man will never be content with the merely good if he sees a chance of attaining something better—otherwise he

would not have become man, and he would still be swinging by his long arms from tree branches. It is impossible to stop progress, however its goal may be obscured by man's uncertainties and weaknesses.

The impossibility of stopping atomic research is surely obvious. The prosecution admits it. It says that control is no real safeguard, that alternative means of the production of bombs may be found, and quotes Germany's secret rearmament between 1919 and 1934. How then shall we arrest *all* atomic research? How shall we gag the scientists of the whole world? What right has any body of men, call itself what it will, to deny men the right to think and discover, to endeavour to arrive at the truths of Nature? Is this the freedom for which the war was fought and won—that freedom which, the prosecution claims, can only be ensured by this ridiculous means?

Surely the answer here is not prohibition or secrecy but greater recognition of the internationality of science and the promotion of the exchange of results between all nations. If all is known, there is little to be feared. It is only when there is ceaseless competition and secrecy, the desire of one nation to outdo the other, that trouble arises. For science is international, and takes no heed of frontiers. Our evidence has been medical, and in medicine progress has always been achieved internationally. Take vitamins. How many know that a great deal of our current knowledge, which began with Hopkins in this country, is due to Japanese scientists? In the case of atomic research, England, Germany, Denmark, Russia, the United States, and France, have all made major contributions, and probably the greatest name in the whole business, that of Rutherford, belongs to a New Zealander. Scientists think internationally and wish to see their work and discoveries common to all. If that aim is achieved, there will be greater safety and freedom from fear.

Stripped of its emotion, its sentiment, its illogicalities that arise from these very things, natural as they may be, the case of the prosecution is seen to be hopelessly weak. It has brought no sound argument against the atom as such, because no charge can stand against an entity which is merely mass and electricity. If the prosecution would arraign those who directed the research leading to the atomic bomb, then it must also indict every scientist in the world war. More, it must arraign statesmen, soldiers, sailors, and airmen. It was war that brought the work to the focus of the bomb. That is the inescapable fact. The brains might, if peace prevailed, have had other thoughts. No-one would set out to make a bomb unless there was a potential or actual need for one.

That indeed is the main line of defence, and we submit that it is unshakable. There is nothing to indict except war. If war can be abolished then knowledge can be turned unreservedly to the betterment of man. But while war is accepted as an instrument of policy, then there must be the diversion of creative forces to destructive ends—as in the case of nuclear energy.

Let us turn from these refutations of a weak case to something more positive. We must weigh the evidence. If the atomic bomb was indeed the only product of atomic research, then the prosecution's case would, in very truth, be inviolable. But apart from its lack of logic, there is ample proof that man has benefited from atomic research for many years. He has gained benefits far in excess of the curses which the bomb has brought.

There are the X-rays, on which we produced somewhat full evidence. There are radioactive substances, which have helped man in his war against cancer. There are all manner of devices in which radiation or the valve are employed. None of these would have been possible if the experimenters had not worked on atomic problems.

The prosecution has alleged that, apart from X-rays, these achievements are negligible on the credit side. Could anything be more untrue? Again, it is asserted that the meagre results, as they call them, are gained at the price of suffering, and that even when it does a little good, the atom wreaks a lot of evil. It quotes the case of Curie and his famous abdominal ulcer.

Here are some large red herrings. Take radioactivity. Certainly it has produced its casualties—but then so have surgery and bacteriology. With the best care and the greatest knowledge, doctors sometimes succumb to the diseases they set out to cure. There is risk in everything. And the dangers of radioactivity were quickly recognized so that they could be guarded against.

Indeed, these very dangers have been the subject of special study. And it is atomic research which in the end is giving the answer to them. Evidence was given of the manufacture and use of the substance known as radiosodium. It bids fair to take away all the potential dangers of radioactive therapy and open a new chapter in this branch of healing. Without fundamental atomic research, this could never have been. The point is worth stressing. Radiosodium was not a research specially to find a means of overcoming the difficulties of radioactive therapy. It arose out of bombardment experiments that were meant to discover, as they did, some of the secrets of the ways in which matter is built up. When the knowledge came, it was turned to useful ends.

Would the prosecution say that anything comparable could occur if all atomic research was stopped? It would be bold indeed to assert as much. Indeed, this is an answer to a large part of the prosecution's case. Atomic research finds its own answers for the problems it creates. If it puts the way of evil in men's range, it also provides something to offset it. And if it has discovered a means of minimizing

the dangers of radioactive therapy, it can surely find another way of slowing down the explosive character of the atom.

Man marches ever onward in his search for truth. He delves ever deeper into the secrets of Nature, and he tries to turn every new discovery to his own purposes. The only thing in doubt is the value of those purposes. When he gains a piece of knowledge he finds, as a rule, that there are alternative ways of using it. When abnormal conditions such as war exist, he may be forced to take only one of those alternatives which may be against his conscience. He may make a force for creation into a power for destruction. That is true of the atomic bomb.

Members of the jury, this is a matter on which there can hardly be any argument when the facts are clearly stated. There is nothing evil in the atom as such, nor in the energy contained in its nucleus. All that is questionable is the use man makes of his discoveries. That is a point to which we shall return very shortly.

Against the so-called evil effects of the two atomic bombs used on Japan there is almost half a century's history of service to man's better interests in the fields of healing and medicine. They are substantial achievements and by no means the dubious things the prosecution would have us believe. These are not matters that can readily be reduced to figures, yet we shall make some sort of attempt, even though they can be little more than guesswork. Even so, a shrewd guess is better than a blunt denial of the truth.

We do not know how many people lost their lives in the bombing of Nagasaki and Hiroshima. It may be put as amounting to thousands. We can say, then, that that is a debit against the atom. But the credit, if less computable, is even more surprising. X-rays have been in use for forty years or more. How many people have owed their

lives to the speedy, accurate knowledge that these rays give in diagnosis? How many of us would have been casualties of the blitz or of the enemy in the field if the doctors had not been able so precisely to see what damage had been done to us? How many people in these years have been saved from the effects of tuberculosis because the X-rays have revealed the spot on the lung which is the portent of disaster?

It must be a large total. Even a conservative guess must put that total alone as greater than the loss of life due to the bombs.

It does not stand by itself. To it must be added the lives of those who would have fallen victims to cancer had there not been radium.

These estimates, crude as they are, are surely conclusive. The possibilities of the future are greater. But they still do not represent all the benefits that man has derived from atomic knowledge. There is, too, the immense amount of suffering that has been alleviated and saved by that same knowledge through radiation and thermionic treatments. That is something to which no figures can be put. It cannot be assessed. But is it too much to claim that by itself it represents something infinitely greater than the destruction of two cities and the devastation of their environs? If human values mean anything, it is not.

Our defence is that the atom cannot be tried. No charge can lie against it for it is incapable by itself of either evil or good. The responsibility lies on man himself. If there must be a trial, if any person or thing must be arraigned, for suffering and death caused to mankind, then the prisoner at the bar should be man himself. He alone has the knowledge of good and evil, as one of the oldest passages in the world says. That knowledge was in the first act of creation as told in the Bible. If man tries to shift his responsibility for good and evil onto unintelligent entities

like the atom or the electron, he is surely accusing himself. If trial there must be, then, let man be tried. Let him be put into the dock so that he may see the enormity of his own crimes against his fellow men. Let him look not at the destruction of two Japanese cities, nor at the havoc in Europe, but at the sacrilege he does to his own being when he turns to war. Let him face the fact that he creates wars, and that equally he can abolish them. Let him, in fact, recognize his duties as man and having done so, turn all his boundless energies to their fulfilment.

He may look into the future and see immense possibilities in this very force that he has used so spectacularly for destruction. He may visualize a world in which the dreams of toiling man come true. It is for him, and him alone, to make the choice, for he alone is responsible for the use he makes of that knowledge which he acquires. Evil is not in things or forces, but in man himself.

CHAPTER SEVENTEEN

SUMMING UP

It is the judge's task not to pronounce judgement, for that depends upon the verdict of the jury, but to hold the balance between the prosecution and the defence. He must put the evidence in its true light without bias. It is a difficult enough task but he attempts it with humility and a sense of full responsibility.

Members of the jury, you have listened with great attention to the speeches of both the prosecution and the defence, and before that you heard the evidence, more particularly that produced by the defence, which, though it was somewhat technical, was not, I believe, beyond the powers of normal comprehension. It is my duty to try to consolidate that evidence and the pleas made, into a form into which you can perhaps appreciate it better and see it in its relative value.

The prisoner is the atom. It is accused of being a menace to the future of mankind, and the claim of the prosecution is that it should be driven out of human knowledge and forgotten. The case for the defence is first that the atom is incapable of being anything but what man directs that it shall be as regards the work it does, and further that on the basis of achievements man is already heavily in its debt to a far greater extent than he has been injured by its activities. There are many subtle points involved, and I shall point these out as I go along.

On the one hand, then, we have the picture that the

prosecution has presented so ably: that of widespread havoc and the mass destruction of human lives on a scale that up till now we have associated only with great national disasters such as earthquakes; and there is, perhaps, an irony in the fact that this disaster should have occurred in Japan, a country well acquainted with the effects of earthquakes. On the other hand the defence has outlined a very different state of affairs. It has drawn attention to the many years during which atomic knowledge has been utilized in the service of healing, and the total effect of that presentation is far from unimpressive.

Your duty will be to strike a balance between the two views. You may think, with the defence, that the prosecution's belittlement of the achievements in medicine went too far, and that it had not that moderation which would commend it to reasonable men and women such as yourselves. Again, you may think that the defence has tended to exaggerate, to claim for these achievements something more than their due. That is one of the questions you have to decide in your own minds.

Before going into the evidence in greater detail, however, I must draw attention to one rather peculiar circumstance. The evidence for the defence opened with a somewhat lengthy exposition of the nature of the atom—to provide, as it were, evidence of character, which in a case of this kind, is obviously of the utmost importance. The arraignment is that the atom is fundamentally evil. Clearly then, evidence of character is of the most material importance. But in the final speech for the defence, little attention was given to this, and I feel therefore that it may be as well if I remind you of it.

The atom, as we were told, is simply an aggregation of various kinds of particles. It started as a simple thing of particles called protons and electrons, but as time went on others were added, so that there were neutrons and

finally such things as positrons, neutrinos, and mesons. The picture grew more complicated as the years advanced, and there seemed to be so great a tendency for the physicists to multiply their particles, calling each one elementary, that an American professor coined the catch phrase: 'What's new in the nucleus?' All this was the result of very active work in many countries.

The point for your consideration, however, is this. This ever expanding knowledge was all in the realm of what used to be called pure science. It was not research for a specific purpose, such as that which industrial concerns undertake to improve their products. This was the pursuit of knowledge for its own sake, and so eager were the early experimenters to press on that they devised the most extraordinary apparatus, since the usefulness of their work went unrecognized and they were given small funds. They had, therefore, to improvise as they could. Despite this, knowledge grew. It is only in Germany before the war and in the United States that really adequate funds were made available for atomic research, yet despite that fact, a great deal of the credit, probably the major part, accrues to the physicists of this country.

All this time, then, there was no thought of atomic bombs. Knowledge was sought for its own sake. The possibilities of atomic energy were discussed, but science was so busy discovering facts that it paid little attention to these practical details. It was not till utter emergency arose that the nations of the western world pooled their resources and spent millions on turning this knowledge to the production of the atomic bomb.

These facts, which may perhaps be new to you, but are well attested and therefore worthy of attention, have a very profound bearing on the case. They seem, on the face of it, to uphold the contention of the defence that there is nothing either inherently good or inherently evil in the

atom or atomic research. It is a neutral thing, and it is man's own choice what the work it shall do may be.

If the men who for fifty years have toiled in this field of science are to be arraigned for a crime against humanity we should have to indict some of the finest intellects that the world has produced. It is not a very encouraging thought.

The prosecution argues that the main achievement of atomic research has been destruction and that the future possibilities are more likely to lie in the same direction than in useful ones. This is a question on which no clear evidence can be offered. It is a matter of opinion, though there are leads in certain directions. You will, if you are to arrive at a verdict, have to take these possibilities into consideration.

What then are the pointers? For some fifty years, it has been shown in evidence, atomic research has produced either directly or as by-products, a whole range of medical treatments and applications, to say nothing of various applications in industry. We have been told and it has been proved that without this kind of research, we should not have our radio sets, though some of you may consider that that might be an advantage.

In the medical sphere with which the evidence has been chiefly concerned, since it is here that the most direct benefit to man is clearly revealed, there have been notable advances through this knowledge. The treatment of cancer has been made more effective, to say the least, and X-rays have increased the powers of the doctor to make a true diagnosis. The prosecution does not deny these things, though it points out the dangers and difficulties that have attended progress and has stressed the doubts that exist in regard to certain forms of treatment. Either these are due to fundamental evil properties of the atom or to lack of complete knowledge; you will have to decide

for yourself, though the defence has brought forward the very remarkable substance of radiosodium in support of the contention that the ill effects of radiation treatments are due solely and simply to incomplete knowledge of the facts and inadequate technique. This is a point to which very full consideration must be given.

The defence has sought to give some sort of numerical value to a comparison of the medical benefits of atomic knowledge with the destructive effects of the bomb. This is interesting, but it omits one very vital point on which none but you can make a decision. It is this: The lives lost in the bombings disappeared in the course of a few minutes at most. Those saved by the treatments are spread over forty or fifty years. The relative rates may seem to you as being of some importance in trying to make an assessment.

But the main question hinges on whether atomic research is an evil thing that must be stopped, or whether it is something intrinsically neutral, the pursuit of knowledge, which cannot be stopped, and that therefore it is for man himself to create conditions under which the knowledge obtained can be put to the most fruitful use.

This opens up very large questions, but I would remind you, members of the jury, that you are the sole judges of fact and that you have it in your power collectively to enforce any decision you may make. It does seem that in the ethical sphere, atomic energy is no different from any other. Man makes destructive weapons and when he has need of them he turns everything to his purpose.

Here we reach the essence of the whole matter and it is the question to which I suggest you devote your fullest attention. The evidence has been given fully enough for you to grasp all the points involved and there is little need for me to review it in any detail. All that need be said is that it must be recognized that atomic energy can be

turned to both bad and good uses and that there is no real means of determining whether the atom, as such, has potentialities more markedly one way or the other.

The difficulties of control or banning of research and experiment have been brought out by both the prosecution and the defence. They are so great that they may well be insuperable.

You have to consider whether man's inquisitive instincts can be shackled. The defence referred to the biblical story of the creation, and you may think that the reference could have been carried further by making the point that in the beginning God Himself could not debar man from satisfying this desire to know.

That is all that need be said in this summing up. It is for you, members of the jury, to decide this issue. You have an old but still vital question to consider: the balance of good and evil and the part that man may play in holding it level.

The verdict is not yet. The jury is the world. Yet it does not seem likely that the atom and atomic research can be judged guilty. It is surely, as the defence contends, that man himself must take the responsibility.

CHAPTER EIGHTEEN

THE VISTA AHEAD

We cannot anticipate the verdict, but it does seem utterly impossible that there can be any other result than that atomic research shall march forward to new triumphs, whether for good or ill. It is the fundamental knowledge of the universe that is being revealed, and its potentialities are too vast to be dismissed as useless. Atomic physics, it may be, is the beginning of the end of man's search for the ultimate, but he is as yet only on the threshold. What vast panoramas the future will show to him it is next to impossible to imagine. The discoveries still to be made can hardly fail to be less spectacular than those already known.

Problems there are; deep and perplexing problems; but certain general principles have emerged, and fresh research will show that much of what is confusing today is in reality merely a further expression of things already known. Atomic physics has grown so rapidly that it is very difficult to see everything in its proper perspective and the parts in their true relation to the whole.

Perhaps the most surprising thing—though really it is not so—is that most of the conventional ideas of matter disappear when we come to the electron. The discrepancies in its behaviour, as, for example, the fact that it sometimes seems to be a particle and at other times to act as though it were a wave, have suggested to some that there is something very wrong about modern discovery,

and that the whole theory should be regarded with scepticism. It is, however, the critics whose thinking is at fault.

These views arise because man has grown used to expecting all things to behave in a similar way to those with which he is familiar on his own standard of size and existence. If he thinks of a particle, he imagines it to be simply a billiard ball infinitely reduced in size, but possessing all the attributes of a billiard ball. If he thinks of a wave, he calls to mind some undulation like that he sees in the sea or river. It is very difficult for him to conceive of anything that might have the properties of them both and still be 'real'.

Yet it is not very surprising that in the electron we find entirely new conditions. It is the smallest known entity and the ultimate part of all matter. We are aware through our senses only of gross matter. Even so, our experience shows that the behaviour of parts of matter, even at the level of ordinary life, is very rarely like that of the same matter as a whole. For example, who could predict from the known behaviour of hydrogen and oxygen, two gases, that together they would form water? That the electron should in some way be different from matter and apparently peculiar is not, then, such a very extraordinary thing.

Again, there is the point of size. It is the lightest and smallest particle or body. Direct observation of it is impossible, both practically and theoretically. It has been shown by Heisenberg that direct observation of the electron cannot be made because it is impossible to devise a system that will not disturb it through the observation. Hence he has formulated the much discussed Principle of Uncertainty, which states that we cannot know with exactitude both the position and the velocity of an electron in space. If we know the one, the other must be uncertain. This is a highly mathematical concept, but the knowledge so far gained is all in support of it. Here it is mentioned

to emphasize the fact that with electrons we enter a new world in which the 'laws' that regulate our familiar world of the senses do not run with the same force.

Our knowledge of the electron is, in fact, indirect knowledge throughout. Its existence and behaviour are deduced from parallel evidence, though it is possible actually to see the effects of electron collisions and similar experiments. That is why, as was pointed out early in these pages, modern science claims only to describe and not to explain; the words 'as if' are at the background of it all.

That the electron acts strangely and not in accord with any sort of particle we can easily imagine is, then, not the surprising thing that many people think it to be. It is no more than might have been expected, for we are dealing with something that has virtually no mass at all and is capable of travelling at immense velocities up to the speed of light. The proper way is to look at the problem from the other end. The electron is the basis of all matter, and matter, therefore, is in some way the result of the electron's properties. If it varies from the laws that pertain to the electron, that is due to its own limitations, and the discrepancy or unexpected occurs when we come to our own level of sense perception. This is a rather difficult idea to grasp, yet it has been proved so in a good many different ways. That of Euclid's plane geometry has already been pointed out. In the stars we are dealing with matter in immense masses; in the atom we are concerned with matter in its most elementary form. We should expect there to be variations in the long range in between.

That electronic laws do, in fact, persist through matter though their effect is masked as we come to higher levels of massiveness is, in fact, now generally conceded. The statement of the wave nature of the electron led to much investigation, and today it is held that all matter, however massive it may be, has wave characteristics. Once

again the proof is largely mathematical, but the principle has the cardinal proof attached to all scientific laws: it describes and systematizes observed happenings and provides a guide for further experiment or action.

These rather abstruse theoretical points are introduced here because it is obvious that the future must bring forth many unexpected discoveries. We are dealing with the unknown and to a large extent unpredictable. We may say from the knowledge at our disposal that such and such a thing is probable, but we can have no certainty that it will be so. There are sure to be shocks and surprises as electronic research proceeds, and as time goes on we may have to adopt an entirely new conception of it which will set all our existing models of it at naught. Here, once again, it may be stressed that there is nothing sacred or certain about these models. They are products of our own minds, and there is, at the moment, nothing beyond probability to show that they are any more than convenient mental pictures to enable us to understand a little of electronic processes.

Electron theory is, then, a field in which much research and progress will be made. It may proceed by revolutionary steps, as in the past, or the next few years may be a period of consolidation and refinement of the knowledge already gained. As things are, the latter seems the more likely event. The chief advance will be made, it seems probable, in bringing together the incompatibles that appear to exist in current theory. This may be done, as so often in science, by the discovery of some new and underlying principle that unifies the two.

Though what has been said here may appear to throw doubt and confusion into the world of the atom, it must not be thought that the theories at present held are in any way invalid or mere figments of the imagination. Every point of them has been tested by experiment, and indeed the very complication of electron theory is due to the

necessity of making full allowance for the experimental results. The original pictures, which fitted in so closely with the behaviour of gross matter as we know it, had to be abandoned stage by stage because they failed to reflect accurately what experiment revealed.

But though we may still be in some doubts as regards the basic theory and great modifications may be expected in the future, the same uncertainty does not apply to the probable advances in the useful fields of electronic application. It is only when we come to consider a single electron that these curious anomalies begin to appear. In everyday life whether at home or in the laboratory, we are concerned not with single electrons, whose behaviour may be erratic and unpredictable, but with the action of millions of these entities acting together. The probability of what they will do and the means of observation are both more certain. We can, from observation, say that a swarm of bees is moving in a certain direction, though it would be difficult to predict the motion of a single bee in the steadily moving swarm. The individual bees fly round and round, up and down, even against the general motion, but the whole swarm moves forward at a steady pace and in a fixed direction.

The whole matter is indeed bound up with the conception of probability. More and more the scientist is abandoning the former use of the word 'law' in regard to natural processes and substituting the word 'probability'. Those who profess to see in science the emergence of a new orthodoxy that may become no less hidebound than the orthodoxies, whether of Church or State, of the past would do well to bear that point in mind. The modern scientist does not say that an event *will* happen; he calculates the degree of probability attaching to its occurrence. When he is dealing with massive things like stars or even tables and chairs, there are so many electrons involved

that the probability is high. But when the single electron is engaging his attention, he knows that he can give very little certainty to his over-all deductions. If one factor in his calculations is certain, the rest must be vague.

One rather notable result of electron research is that it has re-stimulated the interest of the scientist in philosophical questions of ultimate causes and behaviour and sense perception, and enabled some of these concepts to be given a mathematical expression. On the other hand, philosophy no longer sees in science its natural enemy.

The discovery that all matter is essentially the same at this level of minuteness has led in the more practical sphere to a greater trend towards a unification of scientific knowledge, for it is realized that, in the long run, all the interactions of the observable world must arise from changes and conditions in the atomic and subatomic particles of which the mass is built up. This is a very important move in the fundamental sense.

For very many years, science, though unified by sets of basic laws and method, has tended more and more to split apart into self-contained camps, the members of which knew little or nothing of what was happening elsewhere. Indeed, it became fashionable to describe a specialist as a man knowing 'more and more about less and less'. The old divisions of the sciences were themselves subdivided into specialized sciences. While this led to great advances in particular spheres, it meant that the general picture of scientific achievement became more and more confused. There was nothing to co-ordinate it. It was one man's life work to grasp the facts of one particular branch, while it was nobody's business to see if the scattered results of research over this wide area could be co-ordinated and assembled into a satisfactory general pattern.

In the past, when scientific knowledge was so much smaller, one man could carry knowledge of all the sciences

in his head. When the Royal Society was founded in the seventeenth century, its Fellows could discuss all scientific subjects with equal facility and accuracy.

Specialization was inevitable as knowledge grew. The word scientist became a general term that gave little hint of the actual activities of the person to whom it was applied; he might be anything from an astronomer to a palaeontologist. These main divisions again became split. The astronomer could be practically a pure mathematician or a physicist; and a physicist himself might be concerned with the structure of crystals or the behaviour of the atom.

Electron theory has done something towards stressing the need for a new synthesis of existing knowledge. A great deal of our troubles today is due to the fact that there is no unified statement or conception of what science knows and what science can do. Thus, while discoveries in atomic physics are giving us new knowledge and a new and more fundamental control of the physical world, they are also gradually evolving a new and more firmly based philosophy of the world. That philosophy, springing not from the introspection and beliefs of one particular great thinker, but from the facts of the material universe, may well, though perhaps in the distant future, provide man with the chart by which he may set his course through the seas of destiny.

Springing from electronic theory, therefore, there are vast vistas which stretch out to embrace every field of human knowledge. At the moment the clouds of doubt and ignorance obscure all but the main features of this magnificent prospect, and we can do little more than glance at it hopefully. There are certain things nearer at hand, however, at which we can look more closely, and these final chapters will be devoted to a brief inspection of some of the more important of them in the biological and medical fields.

CHAPTER NINETEEN

CONTROLLING LIFE

Despite all man's consideration of the problem, the nature of life is still unsolved. He can do remarkable things in the practical control of breeding of animals. He can conquer disease. But he seems still as far as ever from knowing what life is and even from defining it. It is some very special property of matter that evades his analysis—it may be because he is too close to it. Life has indeed been called 'a disease of matter in decay', as though it was something final and disruptive to which the end must be an oblivion.

It is an interesting question how far modern atomic knowledge, which reaches down into the very fundamentals of Nature, can throw any light upon this age-old problem of light and give man the key he has sought for so long to this problem. No one would dare to say that anything like the solution is yet available, though there are curious hints that it may not be so far off. But already there are indications that modern atomic knowledge may give us deeper and better knowledge of life processes and so enable us to fit in a few more of the missing pieces of the jigsaw.

One of these suggestions is the remarkable sensitiveness of all life to radiation. Moreover, the shorter the wavelength of the radiation becomes, the more the effect on the living thing. Minute single-celled animals like the amoeba of the pond, respond to radiation no less than

the complicated creatures such as man and the higher animals. This is a very important finding.

Its significance becomes the greater when we examine how this radiation works in its effects. In all cases, it seems, it is the cells that are individually influenced by the radiation. Death by radioactive poisoning comes about primarily from a complete breakdown of the cellular organisms in the blood and tissues. Radiation is concerned, then, with the very bricks of life.

As we have shown, under skilled control this process can be used for the purposes of healing, particularly in those conditions where it is desired to destroy disordered parts of the body. Cancers are, broadly speaking, parts of the body that have suddenly started to grow without reference to the rest; the cells multiply at a rapid rate and draw nutriment to them that should be used by the body as a whole. And the disorderly cells are of a special type, simpler than the normal body cells, as if they had degenerated in every way.

Moreover, experiments with these treatments have demonstrated that there is a selective action in the body. X-rays, for example, first stimulate cell life, then slow it down, and finally kill it altogether, and within limits the same is true of radioactivity, though here the radiation is much more powerful, and therefore the stages are less distinct. Certain parts of the body are more resistant to the effects of radiation than others, and, in general, the simpler the cell, the more it responds to irradiation.

These facts, coupled with some others, suggest that in radiation man has a new and more powerful means than ever before of controlling life. He can attack the cells when they are disordered; with greater knowledge he should be able to employ the same means for directing their ordered development and perhaps diverting it into new paths.

That this is not fantastic vision is shown by the remarkable results already attained in dealing with the problems of heredity. Reference has been made to these already. It has been proved that irradiation does produce very marked changes in the genes, the units of heredity, and later experiments have given workers a certain amount of control over the process. The generations of fruit flies can be modified in accordance with design, within certain limits, by irradiation.

This is a field in which linked research between physicists and geneticists would seem to be very desirable. There is much to be learnt not only of the effect of rays themselves but also of the mechanism of heredity. Why rays should produce these changes is at present very obscure, apart from their known effect upon living cells. The method by which they produce these results is unknown, though various theories exist.

Into this situation comes the question of the cosmic rays. They are still somewhat mysterious in their nature and origin, and though the general theory is that they emanate from the depths of space and are a form of interstellar radiation, there is still the possibility, considered more favourably in the early days of their discovery, that they may be generated in the earth's atmosphere. But much more is now known of their character. They are an extremely penetrating radiation of extremely short wavelength, and their action on striking living things is apparently to cause some form of atomic disintegration. An atom struck by these rays throws out an electron and also a positron—a positive electron. Indeed, it was through these rays that the existence of the positron was recognized. The positron has only a very short life.

Now taking all these known facts into consideration, it seems fairly clear that these cosmic rays must have some sort of influence on life. The radiation is short and pene-

trating; and it is precisely this type of radiation which has the most profound effect on the living cell. Moreover, the effect of radiation is dependent on the time of exposure; the question of the time of exposure is perhaps the most difficult in medical irradiation technique.

Every living thing on the earth comes under the bombardment of these rays, not merely at stated times or in special circumstances, but all the time and everywhere. They penetrate to the depths of deep mines and caves, as well as through the waters of lakes and oceans. Wherever life exists it comes up against the cosmic rays.

The theory that they may play the decisive part in bringing out sports and thus encouraging evolution was mentioned in an earlier chapter; but what is the effect on life in general? It may be that life, having grown up, so to speak, under this bombardment has established a tolerance to it, and that they have become, to some extent, an integral part of the life process. It may be found, though this is only guess work, that while present knowledge suggests that the shorter the wavelength of radiation the more searching the effects on the cell, there may be a limit and shorter wavelengths still produce no effect because life in general has become conditioned to the cosmic rays.

This raises the interesting question of what might happen if the cosmic ray radiation ceased. Could life go on or would it take new and strange shapes? At the moment, no answer to this question can be given, but it is clearly one of importance. The problem seems to be to devise effective shields for these rays so that life can be studied under conditions in which their influence is entirely lacking. In view of their omnipresence and their extreme penetration, the difficulties in the way of finding the perfect screen are immense, but it might be that the cosmic radiation could be balanced by man-made radiations, just

as an electric field can be neutralized by another of opposite sign and power.

Cosmic rays offer at once a problem and a challenge to research. It is clear that since they are everywhere, they must play some important part in the universe, and particularly so in the process of living. Too great a bombardment by these rays would almost certainly destroy life if the lessons learnt from other forms of radiation are true. The converse problem of what would happen in their absence is one that may hold important knowledge for the biologist and the doctor.

It is not inconceivable that they play a part in the delicate balance that makes life possible. Modern knowledge shows how small are the limits of physical environment in which life can exist. The most important individual items in living are found to be very small—the secretions of certain glands, vitamins, and the chief dangers to life, like micro-organisms and viruses. Any wide disturbance of these balances, leads to a breakdown of life as we know it.

There are many possibilities, most of them somewhat fantastic imagination, but they are worth stating, for modern science has frequently shown that the most fantastic sometimes proves to be the actual. For example, is disease itself due to variations in the strength of cosmic rays? The cause of cancer is as yet far from fully known. The cells of the affected part begin to proliferate in a quite remarkable way. Again, in general, chemical treatments have not proved very successful, and this suggests that there is something more fundamental at work.

As now more than a suggestion, it might be that the cell life goes on normally under ordinary conditions of cosmic ray intensity, but that variations in it may cause sudden activity of certain types of cells, so that they begin to multiply at a very dangerous rate. The application of

rays by artificial means, through X-rays or radioactive substances, may merely be an attempt to restore the ray balance in the body.

It might be argued that if this mechanism is at work, then a variation in cosmic ray activity, which would hardly be very localized, would affect many people at the same time, and that therefore cancer might be an epidemic or pandemic disease. This does not necessarily follow. It is known that cells within the same body are selective in their response to radiation, and in view of the fact that no two animals—still less any two human beings—are exactly alike in their composition, it could be easily that different people have different degrees of susceptibility to cosmic radiation. In this case, cancer might be caused in people whose cell life was particularly delicately balanced, so that its variation produced very marked results.

Again it must be repeated that this is only a more or less wild guess, though it has nothing inherently improbable about it. The idea is offered as an indication of the way in which atomic research may play a very big part in clearing the problems of biology, from which the atom seems superficially so very remote.

The knowledge that radiation works through the cell is important in many directions. Again looking into the future and trying to see what may happen, there would seem to be a suggestion that through control of radiation man may arrive at the stage when he can modify, according to need, many aspects of life. Heredity is influenced by radiation, as has been said several times here. More knowledge of the genes and their location must give at last a knowledge of how man's inherited endowment is acquired. Radiation treatment may therefore ultimately be a means of eliminating inherited disease and deformity—particularly in the mental field, where its influence is

so strong—and opening the way to a healthier and better race.

At the moment, the control of heredity is possible only in the lower animals by the complicated process of breeding through certain strains whose hereditary characters are well known—pure stocks as they are called. When it is desired to alter these strains or to revitalize them, what is known as outcross is made—a member of the pure stock is mated to one of different heredity. But this is accompanied by certain doubts, and it must be several generations before another pure stock is evolved.

The theory underlying these methods is simple: the aim is to alter the genetic composition of the animals—that is to say, efforts are made to modify the genes. Greater knowledge should enable us to produce the same effect more quickly and more certainly by the aid of radiation directed towards the particular genes with which it is desired to deal.

In man, no doubt, the method, if it is ever perfected, would be used only for dealing with inherited disease. Control of man in the evolutionary sense presupposes an authority that can decide what type of man shall exist, and that in turn involves a degree of dictation of private lives which is far from being in accord with most men's aspirations. But in this direction alone, there are immense possibilities. The toll of inherited diseases is by no means small, particularly in the physical and moral suffering caused by deformity and mental deficiency. It would be a great contribution to the cause of human happiness if these could be overcome.

There is, of course, another avenue of approach to the control of life in general and, in particular, of man's own character and bodily state. It is now well known that the endocrine glands exercise very powerful influences over the body. In deficiency or over-activity they may cause

giantism or dwarfism and distort the body almost out of semblance to human shape, while also producing very unhappy changes in mental make-up. These aberrations of glandular activity may be very small, but their effects are far-reaching. It is believed on good evidence that the very character and nature of a man depends to some degree at least on the balance attained by his endocrine glands.

So far, though much knowledge has been gained, the working of these glands is obscure. Treatments by glandular extracts have proved successful in some cases but disappointing in others. Surgical treatment is often accompanied by dangers and difficulties owing to the vulnerable situations of the glands.

If the relationship between radiation and cell activity could be more fully understood, it might well be that we should have here a method of controlling these glands to a degree not hitherto thought possible. The malconditions arising from glandular inefficiency or over-efficiency do, in general, disappear when the gland working is restored to normal. Irradiation might, therefore, be used either to activate the cell life of sluggish glands or restrict that of too active ones. This is a promising line of thought, for it has already been shown that the action of glands can be restrained by radiation.

There is, too, another process at work in this glandular control: that is not simply the output of the substances of the glands but the susceptibility of the other cells of the body to their influence. Glandular output might, therefore, be normal, but the cells that should respond to it cannot make full use of it. Again radiation, by altering the nature of the cells, might restore the balance.

From this general picture of control of cell activities by irradiation, very wide fields of speculation are opened up. It is known that some people respond readily to

certain drug or chemical treatments, which, on the other hand, quite fail to have any effect on other individuals. This again may be due to the special lack of sensitivity or too great sensitivity of certain tissues of the body—a factor that in turn must depend upon the character of the cells of which it is composed. Here once more the possibility of the uses of radiation to restore a normal state of affairs emerges.

These particular suggestions have a certain amount of interest that is something more than academic, for they arise directly out of existing knowledge of the effects of radiation on the body. From them comes a remote possibility of an even more remarkable kind, though its realization must lie in the far distant future.

It is that through radiation we may eventually be able to control every activity of the human body. Modern biochemistry and modern physiology alike show that the whole human system is one of delicately interadjusted balances, and it is a reasonable supposition that all illnesses and diseases arise from the disturbance of that balance. The fact that a micro-organism or a virus can upset the health of the body in a serious way is evidence that the internal balance has been destroyed.

In its turn, this total balance must rest upon the activity of the cells. These are the units of the body. Some of them have very specialized functions, like the white corpuscles of the blood; others are more general. But deficiency of any one kind must obviously determine the nature of the individual particularly in his divergence from the normal, which may be merely temporary in acute disease, or permanent in chronic ailments.

Complete knowledge of this cellular balance and of the effects of radiation might give the power of ensuring the one by the use of the other. Since all the cellular changes and bodily chemistry are themselves expressions of sub-

atomic activity and atomic reaction, it follows that if we have the means of controlling those processes, we have also the power to direct the more obvious processes at a higher level. We can, as it were, apply the remedy to the very source—and not by imposing external methods but by building up from within.

This internal reconstruction and rehabilitation has been the aim of medicine throughout its history. The idea of the body as a balanced whole, upset of which leads to illness and disease, is as old as medicine itself, even if it has only recently been given scientific confirmation. Atomic research, with its fundamental lessons, may some day show us the way to maintain the internal equilibrium without resort to drugs or operations. This is basic medicine with a vengeance, yet is it impossible—is it even wildly improbable?

Already we have made the first tentative steps in the right direction. There have been failures and disappointments—all too many of them. But the majority of these have subsequently been cleared up as greater knowledge has become available. They are the products of ignorance rather than a false approach.

What clearly emerges from these considerations—which some may think are unduly fantastic though really they are not so—is that the need today is to link all kinds of research together so that progress in one field is reflected by advances in every other one. This is particularly necessary with atomic research. This is the science that is giving us knowledge of the fundamentals of Nature, the way things are made, and the processes by which everything works. Biology and medicine are sciences which are concerned all the time with change and decay, and the need for the explanation of these processes in basic terms is very real. The day when one science could be considered independent of another, or at best ready only to

use those results of another branch which seemed useful, must be considered past if real progress is to be attained.

Atomic knowledge then, showing us how to control matter, and through matter the cell and the living process, may show the way to a new science of healing in which the highly complicated and largely empiricial methods of today find no part. If it is no more than a dream, it is surely a dream worth the having, an ideal for which to strive. Until man controls himself and his ailments, he can never hope to gain that complete mastery over Nature which it has ever been his aim to exert.

CHAPTER TWENTY

NEW METHODS IN MEDICINE

The developments indicated in the last chapter are those which, if they ever come about, must lie in the far future. What are the prospects nearer at hand of using modern atomic knowledge for improving the science of healing?

This is a question of practical importance, but it is also one that is more difficult to answer. It is often easier to see things at a distance than to study them close at hand. The detail then tends to obscure the general picture.

It is clear that one of the most promising of the near-at-hand advances must be the improvement of artificial radioactive substances. This is so important a discovery that it is almost impossible to exaggerate its probable influence for good. The difficulties of radioactive technique are formidable enough, not merely in application, but also in the variability of result. The introduction of radioactive materials means that some of the difficulties at least are smoothed away, while a much greater certainty is obtained. It is not that radioactive treatments are themselves failures. Rather it is that secondary induced effects are not so much within control as might be wished.

This point has already been made at some length, and there is no need to repeat it now. But it may be stressed that so far radiosodium is in use to an extent even more limited than that of radium, and we are, therefore, only at the starting line with the race barely begun.

The lines of advance in this field would seem to be many. The great underlying discovery is that it is possible by certain means to make ordinary non-radioactive substances emit radiation of a kind that can be used therapeutically. This means that, if the radioactivity is only temporary, the body has nothing left to deal with but substances it is able to assimilate without harm.

Thus radioactivity is brought much more under control. The possibilities of making all substances radioactive is not remote, and indeed the range is ever increasing. It may eventually be found that by suitable bombardments, any desired element can be turned into a radioactive one.

Here there are important implications from the medical point of view. In the first place, it is almost certain that the different radioactive isotopes of ordinary substances will have widely differing half-life periods—that is to say their temporary radioactivity will endure for widely differing times. This gives at once a new method of close control of dosage. If only a small degree of irradiation is required, then a short-lived substance can be employed; if a longer treatment is necessary, then a substance with a longer activity can be adopted. There would be a range from which almost any desired period could be chosen.

Again, there is the possibility that radioactivity may be found to have other effects on the human system besides those mentioned. Drugs are given to the human being for the purpose of stimulating, usually by chemical means, this or that function, or reducing another—or alternatively for restoring a balance, as in the digestive system, which the faults of the bodily working have upset.

What would be the effect of radioactive drugs? Would they stimulate or inhibit to a greater or less degree than the non-radioactive counterpart? Here we draw near again to the control of cell activity by radiation. It might be

that a radioactive drug could produce the effect of the normal drug, and at the same time produce required cell changes that would make the drug action more efficient. The ground might be, so to speak, prepared for the reception of the drug.

Before anything like this would be possible, a vast amount of research would have to be carried out. There are many variables involved, and the work would have to proceed slowly, for it is an undoubted fact that in the public mind, spectacular early failures far outweigh the mass of good results won later. Yet it is a promising and suggestive field of inquiry that should not be neglected.

Thus, the *materia medica* of the future may consist of both radioactive and non-radioactive drugs of the same chemical formula, and new ways of treatment of extraordinary efficiency may become available, because they are more fundamental and treat causes rather than symptoms.

One interesting point hitherto not mentioned is that these artificially radioactive substances differ, in some cases, from naturally radioactive ones in that they emit positrons—the particle of positive electricity. Now electrons and positrons are fast moving and therefore highly penetrative. A radioactive substance emitting positrons should have high penetrative power and be, therefore, more effective than one which gives out the slow-moving alpha-particle. This leads to another point in that it brings to light the interesting fact that so far next to nothing is known of the effects of charged particles of opposite sign. Apart from range of penetration, there appears to be little difference between the effects of positively charged alpha-particles or protons, and those of electrons. Further it has been shown that neutrons, which carry no electrical charge at all, are highly effective. Does, then, the influence of radiation depend simply upon the bombardment?

Does the nature of the electrical charge play no part in the curative or destructive work?

These are questions to which fuller attention must be given. It may be found that the electrical charge does play some part in the process, even though that effect is largely masked by the mass effect of the bombardment. If this is found to be so, it may increase the applicability of radiation treatments still further, by indicating that in one condition positively charged particles are most efficacious in other negative particles, and in still others, the neutral neutron may prove the best. These are hypothetical suggestions, but they do tend to bring out how much work remains to be done in the field of radiotherapy.

One of the difficulties, as already mentioned, attending the use of radiosodium is that it must be freshly prepared. In other words, means must be available at the hospitals for bombarding sodium so that the radioactive form can be obtained on the spot. This is chiefly a question of finance, but it does also suggest that the physicists themselves must, if their discoveries are to be put to their fullest use, develop better, simpler, and cheaper methods of producing the required elements.

Of course, it may be that the lessons learnt in the manufacture of the atomic bombs have contributed something to the solution of this problem. All that is known at this time is that the production of atomic bombs is costly and involved. But at least one fact emerges from the atomic bomb research and it is a point of some importance in connection with this matter of radiotherapy.

The whole secret of the atomic bomb is that means have been discovered of controlling the rate of atomic disintegration. Now radioactivity is neither more nor less than atomic disintegration through the breakdown of the nucleus. Methods of control and retardation might, therefore, be developed—and indeed must be developed if

nuclear energy is ever to be utilized for peaceful and productive purposes—so that the activity could be maintained at any desired level.

This immediately suggests new ways in medicine. If radioactivity is thus brought under close control—if the bombardment of bodily tissues by electrically charged particles or neutrons—can be brought even to the same degree of exactitude as obtained today in X-ray technique, a very great advance will have been made. It might, in fact, solve the difficulties of the production of artificially radioactive materials on the spot, for the control available might be sufficient to enable the radiotherapist to obtain any degree desired of radiation from one standard substance, just as the physician can dilute drugs to get the required concentration suitable for each case.

In all radio therapeutics, then, the path to progress leads through the thickets of control, which, at present, seem almost too thick to penetrate. These problems may be solved on the one hand by the production of a wide range of artificially radioactive substances from which may be selected one that has the desired characteristics to suit it for the case in hand. On the other, there is the possibility that methods of control of the decay of atoms may attain the same end by different means. But the clamant need today is for greater accuracy of control over radiation.

Another possibility, though a much more remote one, and suggested by artificial radioactivity, is that by suitable irradiation the actual tissues of the body might be rendered radioactive, and so, as it were, be led to cure themselves. This may be nothing more than a vague suggestion but it does arise directly out of the implications of modern research.

One big question is latent in the discovery of the atomic bomb. What effect could nuclear energy itself have on the

human body? We know that it has violent destructive and poisoning power. Could it have any influence for good?

This is a question to which data available now do not give an answer. It again comes down to the problem of control. The emission of particles from radioactive nuclei is, in a sense, nuclear energy, but it is not so in the fullest degree. Nuclear energy, so far as we know at the moment, would have the effects of very intense radiation of extremely short wavelength. We are brought back to the unsolved problem of cosmic radiation and its effect on the living process. Could these extremely short wavelengths kill or cure? Thus it is seen once more how all problems interact with each other, and the need for interconnected research is made the plainer.

Ordinary progress in atomic research will undoubtedly lead to the placing in the hands of medicine new and more powerful weapons in the fight against disease and suffering. The progress in diagnostics is likely to be particularly noticeable. X-rays have proved one of the most valuable tools of all in the hands of the doctor for determining internal conditions; other types of radiation may lead equally to still further possibilities by enabling the diagnostician to see structures that are at present hidden.

The electron microscope, if developed so that it can be more readily available, will throw light on the behaviour of the ultimate composition of the body and thus in turn lead to that fuller knowledge which alone can make us masters of disease and health. It should make possible asking the most intimate questions about living processes and even the discovery of the nature of life itself.

One may say, therefore, that progress in atomic knowledge has led to many and great benefits to the art of medicine and has tended to make it more and more a science and less and less of a highly specialized craft in which the chief qualification has been wide and deep

experience. That is all to the good, since it means that the benefits of modern treatment can be more widely disseminated than those of the older form.

It is fifty years since Becquerel discovered radioactivity. It is about the same time since Sir J. J. Thomson proved the existence of the electron. In that period the world has been transformed. Not the smallest beneficiary of this new knowledge has been medicine which has found in X-rays and in radioactivity valuable new techniques of diagnosis and treatment, and which has kept in step with the march of progress by making use of new atomic discoveries as they have become available. Today we have added to the simple X-ray tube all manner of refinements that give it a wider range of usefulness and also eliminate many of its former disadvantages. We are employing artificial radioactivity to enable us to obtain the good results inherent in radium without their attendant evils.

In the next fifty years the progress will be all the greater. The paths on which we have started to tread will broaden into wide roads along which we shall be able to move faster and more freely. We shall replace empirical knowledge by hard fact, uncertainty by certainty. New methods reaching down to the basic causes of disease—which are only an expression of the unending change of matter—will be discovered and bring in sight the final conquest of suffering. Whether they will yield, too, the secret of life and death is beyond imagination. It may be so; and then it will be that man will be faced with the most stupendous question he has ever had to answer—whether immortality in the physical world would be worth while.

We can look on the atomic bomb only with horror. It was the climax of the most terrible war in history. Yet it may be that that very horror has given man knowledge that he will be able to turn to his ultimate high advantage, and that the legacy of six years' carnage may be a greater

freedom from pain and suffering than he has ever known. It would not be the first time that a greater good has come out of a great evil, and that man has found the way to better things through the pangs of agony and disaster.

In these last two chapters we have dealt only with the medical and biological aspects and their promise in the future. The possibilities elsewhere are even more immense, but their treatment would be best left to the hand of another more versed in the problems of industry.

EPILOGUE

Let us look back on the journey we have made together —a journey that has taken us through strange country and revealed many unusual and unexpected sights.

We started with the grim impact of the atomic bomb on the conscience of the world, and we set out to show that, evil though that bomb is, the knowledge on which it was based was not in itself evil, and that it had not merely within it the seeds of good, but that those seeds had already come to first flower. We looked into the structure of the atom, so far as simple men might, and witnessed some of the curious things that exist there and studied some of the extraordinary forces at work.

Then, leaving for a moment the factual paths of science, we staged an imaginary trial. We put the atom in the dock and we listened to speeches from counsel for the prosecution and the defence and to the summing up of the judge.

Finally we glanced into the future, not with the eyes of a romantic novelist but through the sober spectacles of scientific probability. The things we saw may not be realized, for no man can prophesy the turn that human history may take. But any rate they are possible, and if they are only partially realized then the benefits to mankind will be great indeed.

When we concluded our small trial scene, we said that the verdict was not yet. The world must judge on what it will do with the knowledge that the atomic bomb has brought. The jury has retired and is considering its verdict.

Yes, that jury is composed of the men and women of the world, of doctors like myself and scientists, of labourers and artists, of politicians and tradesmen, of soldiers and cooks. There are black men and yellow men and red men on it as well as white men. For the destiny of man is the concern of man himself, and he must, in the long run, decide it for himself.

It is wrong to anticipate the verdict of a jury. In this country to do so is to commit an offence. But this is something beyond the laws of this country. The principles of humanity are at stake. And the jury is composed not of twelve good men and true, but of the whole world. I am a member of that jury. You are a member of that jury. You and I and millions of others are met together to discuss the evidence and the summing up, to consider our verdict. It is right, therefore, that every voice should be heard. That is why, now, when the facts have been outlined, I propose to reveal my own mind. I wish to make my small contribution to the discussion, not in the form of facts—which, indirectly, I have done in the foregoing pages—but in the expression of my own opinions. If I do so in public, I commit no crime, for, as I have said, the whole world is the jury.

What do I believe? Do I think that we can halt the onward march of knowledge? Do I consider that, if we could do such a thing, it would be desirable in this one case—or in any case? Do I contend that atomic knowledge is evil, something that will again cast man out from the paradise to which God originally assigned him?

These are the questions, among many others, that you and I and other members of the jury must answer. They involve a lot. But the atomic bomb has shown that the answers we shall make to them will decide the future of mankind himself—will, in fact, determine whether man is to survive or whether the earth is to be left, as some

cynics have claimed it should be, to the multitudinous insects and the mechanical, soulless efficiency of the termite.

Let me say that I do not believe for one moment that the onward march of knowledge can be halted. Not only do I believe that to be impossible, but also I hold that to attempt to do so would be the greatest of all sins which man could commit against himself and creation. Without knowledge man could not be, and it is only through knowledge that he can, in the long run, purge himself of those evils in him which the last six years and more have made so evident.

It must be full knowledge—the knowledge not only of good but also of evil, for he cannot attain the former unless he is aware of the latter, any more than he can make his way across a quicksand without knowing which are the solid patches and which the treacherous. The more knowledge he gains, the more his power to do good must increase. He can fulfil himself and his purpose only by looking unblinkingly on the black as well as the white.

And it is impossible to destroy knowledge. Whatever is done, it lingers ready to spring to life again as soon as the opportunity comes. The great library of Alexandria, where all the books of the world were gathered, was burnt; and a million volumes or more perished. But that did not arrest learning. The medieval Church burnt Galileo at the stake. But the system which he had discovered as that of the world lived and today the veriest schoolchild knows that the earth moves round the sun.

So it is with atomic knowledge. It cannot be swept away. It cannot be stopped. Nothing would do more to plunge the world again into anarchy than some miracle by which all our knowledge of the atom and its potentialities could be utterly destroyed.

For there is nothing in that knowledge which is inherently evil. It cannot be. Those are the thoughts I have

tried to put into the words of the speech for the defence in this book. Shall I admit now that it was I who was speaking? Evil and good cannot be applied to knowledge as such. Knowledge enables one to differentiate between good and evil, but is not either in itself.

There was a time when the alchemist, from whose crude work has sprung in the long run the marvels of penicillin and transmutation, was regarded as in league with the Devil, and all his works were looked upon as sin itself. But they were not. He made more errors than he found truths. But neither his errors nor his truths were good or evil.

But I go further than that in my view of atomic knowledge. I have tried to assess its potentialities. I have endeavoured here in this book to give an outline of what such knowledge has done and can do in my own little field of medicine. And I can see there nothing but potentialities for good, resting on a basis of high achievement in the past fifty years. If I personally set this achievement against the horrors of the bombs, I still find that the achievement is the greater, for there is value beyond computation in one human life saved from death and suffering.

Let us look at it in this way. The atomic bomb has destroyed lives on a vast scale. But it has done so only because man so ordered that its energy should be directed in that particular way. If those bombs had not come, those thousands of lives might still be in existence. Look at them. They are human lives, whether Japanese or white. They would be subject to all the disease and illnesses that are the burden of man in the world. And to the alleviation of those ills all the treatments and aids I have briefly described in these chapters might have been brought.

Suffering, death, disease, are in the world without man's intervention. Atomic knowledge enables us to mitigate those evils and will be more and powerful as time goes

on. Radioactivity—X-rays—these and the rest are natural weapons in our hands to combat disease. Nothing which has those potentialities can be a force, a drive—call it what you will—to evil.

These are some only of the rich promises that atomic knowledge holds out to us. Man alone has the power to take them and use them and turn them into realities for his own betterment. He has used them for destruction. Very well, then. Let us face up to that fact—and let us also see what that destruction in itself may force upon him.

It has shown him what nuclear energy can do. It has shown him what immense powers his talents have won for him. More than that, it has awakened his sleeping conscience. It has brought him hard against the fact that if he takes to killing he must go on until there is nothing left to kill or maim. He knows now that if he makes the age-old mistake of trying violence, he, wherever he is, will face annihilation not only for himself but for his children. He will have decreed the end of man.

Even in this war some of the old glamour of warfare remained. We still give the fighting man a godlike status placing him above his fellows. While we deplore in speech and writing the evils of war, our eyes light up and our feet are set tapping exultantly by the music of the military band. The uniform is a sign of honour to us. That is all very well. I do not quarrel with the thoroughly good belief that the men who face the risk should be treated best of all.

But that era is passed. Two small aeroplanes could wipe out the biggest city in the world. There would be no unfurling of colours, no rhythmically marching feet, no music. The glamour of war has gone. War is now seen to be what it has always been beneath the panoply—death and suffering.

In the air raids every civilian became, for the moment, a soldier facing sudden death. He could fight back with

his measure of relief. In atomic war every civilian will be just a sacrifice—and that is all.

So this new bomb has brought man to the real decision —the one he has always been on the point of making, but has always retreated from at the slightest provocation. He must destroy, not other nations, but war.

Those are high-sounding phrases—oh yes. They have been said in various forms many, many times. But they can be uttered now in a spirit of greater conviction and with a far greater hope that they will be heeded than ever before.

But how is man to do this great thing? How is he to destroy war?

He must bring better conditions for all men, white or black, brown, red, or yellow. He must give the good things of the earth to everyone. Again those are high-sounding phrases. Have they any hope of realization?

The answer to that lies in—atomic knowledge. With that man goes into the very heart of things. He comes to grips with the stuff and energy of which all things are made. The key to power is placed in his hands. He can unlock the store and let it all loose so that man is destroyed by a glut of energy, or he can husband his resources, turning them to good use.

For what the atomic bomb teaches is that at last man has come to the end of his road that leads to the search for control of Nature. He has discovered the fundamental secret. He has now the knowledge that can enable him to do all things, and he must prepare himself to use it wisely and well.

The threat to mankind is not the atomic bomb but man himself. He can study objective Nature and wrest its secrets from their mysterious wrappings. Now he must battle with a more difficult problem. He must wrestle with himself and gain control over his own evil desires as he has over the blind forces of Nature.

That is indeed the whole thing in a phrase. The forces of Nature are blind, needing direction. On this earth it is man and man alone that can give them eyes, point the way they must go, make sure that they do not run amok. He has done it already in some remarkable ways. He has canalized the raging torrent and caused it to make mills go round. He has mastered the molecular energy of steam and petroleum. Now he must do the same for the atom. It is his great task.

No, I do not believe that we can check the growth of this knowledge. Nothing would induce me to lend a hand to try to do so. On the contrary, I would do all in my power to hurry research forward, to pour out on our laboratories some of the vast wealth we can always find for the prosecution of wars.

My work in life is to do what I may to relieve suffering and rob death of some of his possible victims. It is with the aspects of atomic research that I look on this problem that I have dealt with here, because they are nearest to me. I see in this knowledge an ever expanding means of doing better and better those things which I strive daily to do with the inadequate knowledge at my command.

I said 'inadequate'. It is inadequate for two reasons. One is that I am human, and no one man can contain within him all the wisdom of the world, so there are times, perhaps too many of them, when my skill falters and is not all it should be. But that is only a personal reason and becomes the less effective as my experience grows—and with it my humility and realization of deficiencies.

But the second reason is more important. Time and again I and every other doctor has to confess to himself that he wished there was other knowledge available on this or that subject. Why is it not so?

There are men and women eager and hopeful of doing research. They are working at these very problems in every

medical centre in the world. But what a pitiful shadow their work is of what it might be and should be! They progress slowly where they might forge ahead because their resources are not big enough. They improvise when they should have everything they need. Often their personal efficiency is lowered because their own salaries are barely enough to enable them to live full lives.

This is the picture of research. It is not overdrawn. What it needs is money, and nowhere more than in the atomic field which is revealing the heart of natural processes to us. That is expensive work. No-one knows the full cost of the atomic bombs. It was immense, but it gained the desired end.

There is the great lesson that man has to learn. He must realize more than ever before that a happy life, a full life, a life free from disease and suffering, can be his if only he will pay the more exorbitant price. But he is misled. He pours out his wealth and his energy to wage war. As soon as the war is over, he says never again, but he does little or nothing to turn his wealth and energy to making that better world in which wars would be unnecessary.

For it is with man himself that wars begin. No amount of material comforts will, by themselves, end war and destruction. The germs of war are in fact in them, for those people who do not enjoy them will claim their share by force if necessary. It is in the mind of man that the idea of war begins and through the same agency the whole vast machinery of devastation is set in progress.

The really fit and normal man would not want wars. He would not listen to those who talk of war. He would regard them as the lunatics they are. No-one has preached the gospel of war more fluently than Adolf Hitler and his colleagues—and all of them were pathological cases with recognizable symptoms in their behaviour.

Full knowledge such as wide research into the fundamentals of matter and life would make such people as Hitler impossible. That is what I have tried to show in part of this book. Through full knowledge we can remove the evil and the harmful from man and restore him to the state of grace that was his in the Garden of Eden.

Beyond the realm of medicine, there are many benefits that atomic knowledge can bring. Above all it can give abundant power—and by that the slavery of manual labour in its worst forms can be eliminated. Abundant power means cheap and abundant goods of all kinds. More than that, knowledge of atomic processes will make possible the evolution of new materials, new substances, that may give life an entirely new trend.

Man cannot go so far and no farther to this work. He must forward it with all his powers of brain and money. He must look steadily into the future and see that he controls himself above all.

Let us cease this talk of an 'evil' atom. Let us stop mouthing sentimentalities about going too far into the secrets of Nature. The plain truth is that man cannot go far enough into the secrets of Nature, that the more he learns the more he can organize his own betterment. He can, if he so wishes, order a world in which suffering is almost unknown. He can build up a world in which plenty is the commonplace. He must prepare himself for a revolution in his thought as well as in his mode of living.

These are some of the things that he can win if he will see to it that his own knowledge is turned into the proper channels. A generation hence man will laugh at our talk of the curse of atomic knowledge. Instead they will regard it as the boon it is.